N05-A Pipeline design

Basic Design Report

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N05A-7-10-0-70029-01

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Project

N05-A Pipeline Design

Document

Basic Design Report

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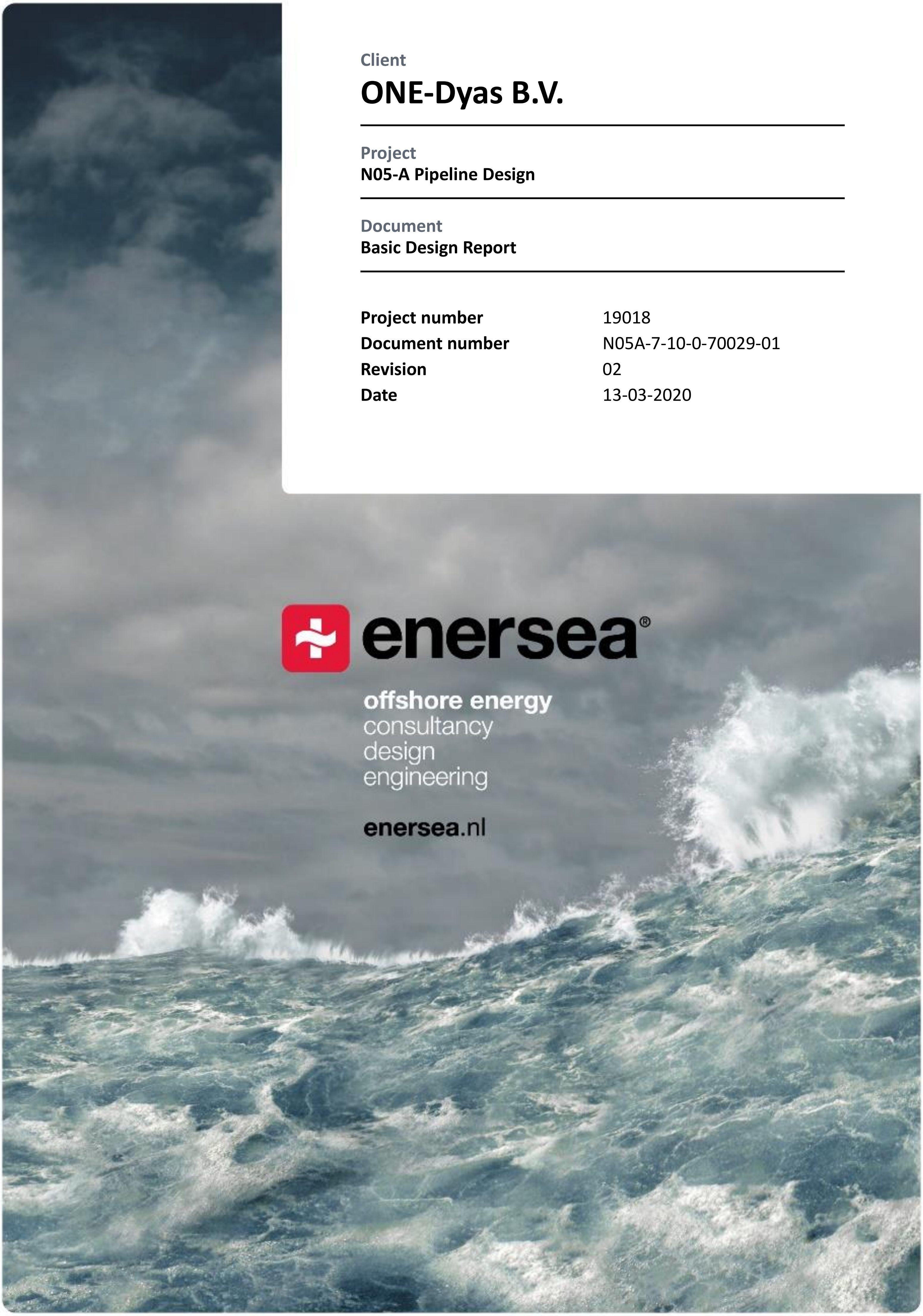

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01	For client comments	31-01-2020				
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Table of content

1. Introduction

1.1. Project Introduction

One-Dyas plans to develop a successfully drilled well in block N05-A of the North Sea Dutch Continental Shelf. More wells will be drilled at this location through the same jacket. It is planned to develop the wells by installing a platform and a gas export pipeline with a connection to the NGT pipeline @KP142.1. The approximate length of the pipeline is 14.7 km.

In addition, a power cable will be installed from the Riffgat Windpark to the N05-A platform.

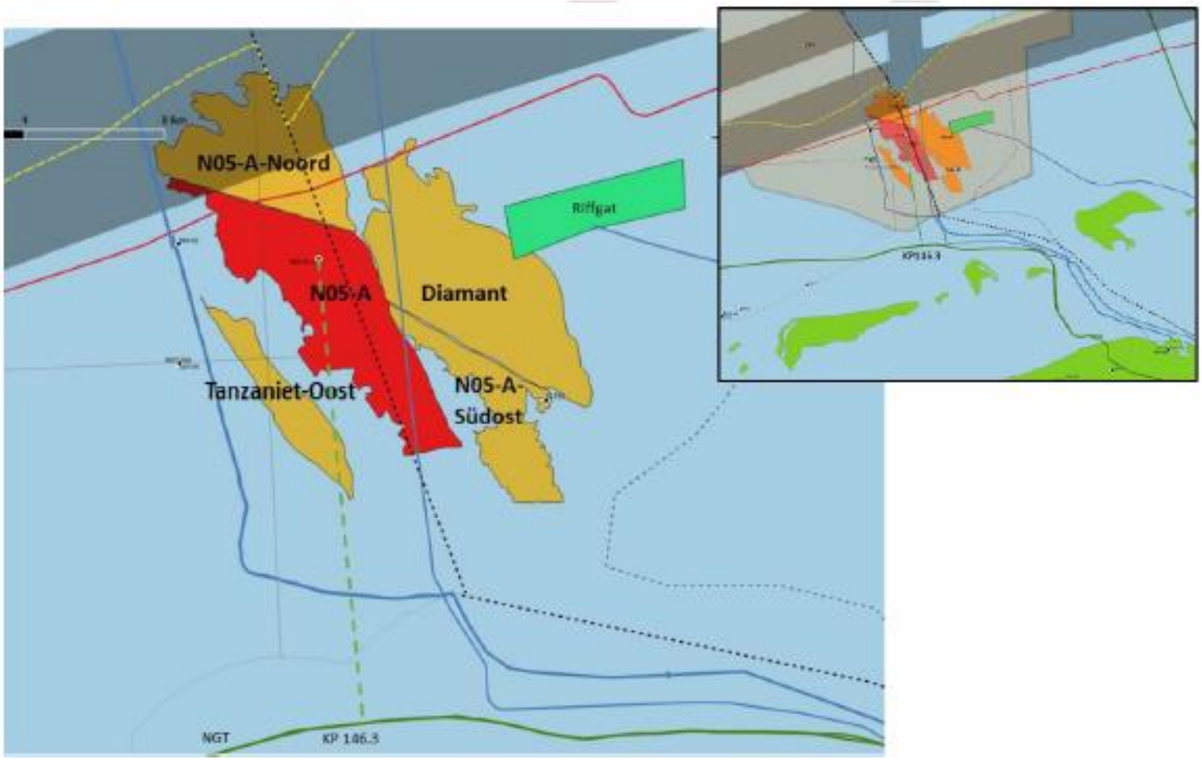


Figure 1, N05A Field layout

1.2. Purpose and Scope Document

The Basic Design Report documents the results of the calculations for the flowline, including:

- Wall Thickness analysis
- On-Bottom Stability analysis
- Buckling & Collapse analysis
- Static & Dynamic Free Span analysis
- Bottom roughness analysis
- Upheaval buckling analysis

1.3. System of Units

All dimensions and calculations shall be documented using the International System of Units (SI) unless noted otherwise.

1.4. Abbreviations

BoD = Basis of Design

FEA = Finite Element Analysis

LAT = Lowest Astronomical Tide

MTO = Material Take Off

TB = Target Box

TOP = Top of Pipe

VIV = Vortex Induced Vibrations

WD = Water Depth

1.5. References

1.5.1. Regulations, Codes, Standards and Guidelines

[1] NEN3656:2015 “Eisen voor stalen buisleidingsystemen op zee” December 2015

[2] DNV-OS-F101. “Submarine Pipeline Systems.” October 2010.

[3] DNV-RP-F105. “Free Spanning Pipelines.” June 2017.

[4] DNV RP-F107. “Risk Assessment of Pipeline Protection.” May 2017.

[5] DNV-RP-F109. “On-Bottom Stability Design of Submarine Pipelines.” May 2017

[6] DNV-RP-F110. “Global Buckling of Submarine Pipelines” April 2018.

[7] DNV-RP-C203. “Fatigue Design of Offshore Steel Structures.” April 2016.

[8] DNV-RP-C204. “Design against accidental loads.” November 2014.

[9] 21. American Lifelines Alliance. “Guidelines for the Design of Buried Steel Pipe.
ASCE July 2001.

[10] ASME Boiler and Pressure Vessel Code. Section VIII Rules for Construction of Pressure vessels. Division 1. July 2013.

[11] Design of Submarine Pipelines Against Upheaval Buckling OTC 6335 by A.C. Palmer e.a. May 1990

[12] DNVGL-RP-F114 – “Pipe-soil interaction for submarine pipelines”, May 2017

1.5.2. Company Engineering Standards and Specifications

1.5.3. Project Reference Documents

[i] N05A-7-10-0-70028-01-02 – “Basis of Design Flowline”

[ii] N05A-7-10-0-70031-01-01 – “Route Selection Report”

[iii] N05A-7-51-0-72510-01-04 – “Overall field layout drawing”

[iv] N05A-7-50-0-72019-01-02 – Approach drawing @N05A

[v] N05A-7-10-0-70032-01-02 – “Approach drawing @NGT

[vi] N05A-7-10-0-70027-01-03 – "Flow Assurance Design Report"

[vii] N05A-7-10-0-70036-01-01 – "Flow Assurance Design report - Transient Analysis"

[viii] N05A-7-10-0-70035-01-01 – "On Bottom Stability Analysis Design Report"

[ix] Metocean Criteria for the N05A Platform – 181892_1_R2

[x] Metocean criteria for the N05A Platform Side Tap – 191146_1_R2

[xi] N5A VC-C-7 S-3 0300m CID

[xii] N5A VC-P-3 S-2 0405m CID

[xiii] N5A VC-P-8 S-4 0240m CID

[xiv] No5A-7-10-0-70030-01-02 Risk assessment dropped object analysis

[xv] 19018-10-PRE-01001-02-02 N05-A Progress meeting + Minutes of meeting, 2019-11-07

1.6. Holds

2. Summary

This document reports on the basic design stage of the flowline from the N05-A platform to the tie-in with the NGT pipeline. This includes:

- Wall Thickness analysis
- On-Bottom Stability analysis
- Buckling & Collapse analysis
- Static & Dynamic Free Span analysis
- Bottom roughness analysis
- Upheaval buckling analysis

The wall thickness analysis showed that a wall thickness of approximately 15mm would be required. It was chosen to select a wall thickness of 20.62 mm. The extra steel weight will assist the stability of the pipeline, which is further documented in a separate report (ref. [viii]).

The maximum allowable spans following from buckling & collapse and static and dynamic span analyses are determined for three depths: 8, 17, and 26 m (LAT), which corresponds to the water depths at the end, approximate middle, and start of the pipeline, respectively.

Criterion	8 m	17 m	26 m
B&C – bending and external pressure – Maximum span	62.6m (install/hydrotest) 76.7m (operation)	59.2m (install/hydrotest) 53.3m (operation)	56.0m (install/hydrotest) 43.8m (operation)
Static free span	66.3m (install/hydrotest) 91.3m (operation)	63.1m (install/hydrotest) 61.4m (operation)	60.1m (install/hydrotest) 52.1m (operation)
Dynamic free span: in-line VIV	21.9m (install/hydrotest) 20.9m (operation)	22.9m (install/hydrotest) 21.6m (operation)	25.2m (install/hydrotest) 23.7m (operation)
Dynamic free span: cross-flow VIV	36.0m (install/hydrotest) 35.3m (operation)	33..0m (install/hydrotest) 30.8m (operation)	37.2m (install/hydrotest) 30.7m (operation)

The bottom roughness analysis showed that the as-surveyed seabed will result in 1 span that is of unacceptable length during the installation phase. This span (27m) is present at KP0.4 at 26 m of water depth (section 9.3). The span criterion is based on in-line VIV, which could be mitigated if the pipeline dynamic response is investigated in the detail design phase.

Finally, an analytical upheaval buckling analysis was performed to determine a relation between the sand cover, imperfection heights and vulnerability to buckling under operational conditions (section 8.1).

3. Design Parameters

This chapter describes the design data to be considered for the pipeline (incl. spool pieces near the riser and the hot tap) from the new N05A-Platform to the NGT pipeline.

3.1. Pipe Data

The basic line pipe design and spool piece data to be considered in the analysis for the export gas line are presented in Table 3-1. Steel material properties considered in the design are presented in Table 3-2.

Property	
Product transported	Natural gas (dry)
Design life (years)	25
Approx. length (km)	14.7
Material grade	L360 NB
Manufacturing process	HFIW
Pipe outside diameter (“)	20”
Pipe outside diameter (mm)	508
Pipe internal diameter	466.76
Wall thickness (mm)	20.62 (Sch60)
Wall thickness tolerance (%)	7.3
Wall thickness tolerance (mm)	+/- 1.5mm
Internal corrosion allowance (mm)	3
Anti-corrosion coating	3LPP
Anti-corrosion coating thickness (mm)	3
Anti-corrosion coating density (kg/m^3)	930
(Concrete) weight coating thickness (mm)	N.A
concrete weight coating density (kg/m^3)	3300
Minimum hot bend radius (mm)	2540 (5D)

Table 3-1 Pipeline data

Property	
Material	L360NB
Density (kg/m3)	7850 kg/m^3
Specified Minimum Yield Strength at 20°C (MPa)	360
Specified Minimum Yield Strength at 50°C (MPa)	360
Specified Minimum Tensile Strength (MPa)	460
Young’s modulus (Pa)	2.07 x 10^{11}
Poisson ratio (-)	0.3
Thermal expansion coefficient (m/m·ºC)	1.17 x 10^{-5}

Table 3-2 Material properties

3.2. Process Conditions

Table 3-3 presents the pipeline and spool design process parameters considered in the analysis.

Property	Export gas line
Design pressure	111.1 bar(g)
Operating pressures	95 bar(g)
Design temperature (min / max)	-20 °C / 50 °C
Operating temperature (min / max)	1 / 43 °C
Ambient (air / surface) temperature	-6.8°C / +24.2 °C
Content density (arrival, nominal operation)	88.7 / 96.1 kg/m³
Design flowrate (min/max)	0.14 / 6.0 MMNm3/d

Table 3-3 Process design parameters

Figure 3-1 shows the operational thermal profile along the pipeline, ref. [vii] .

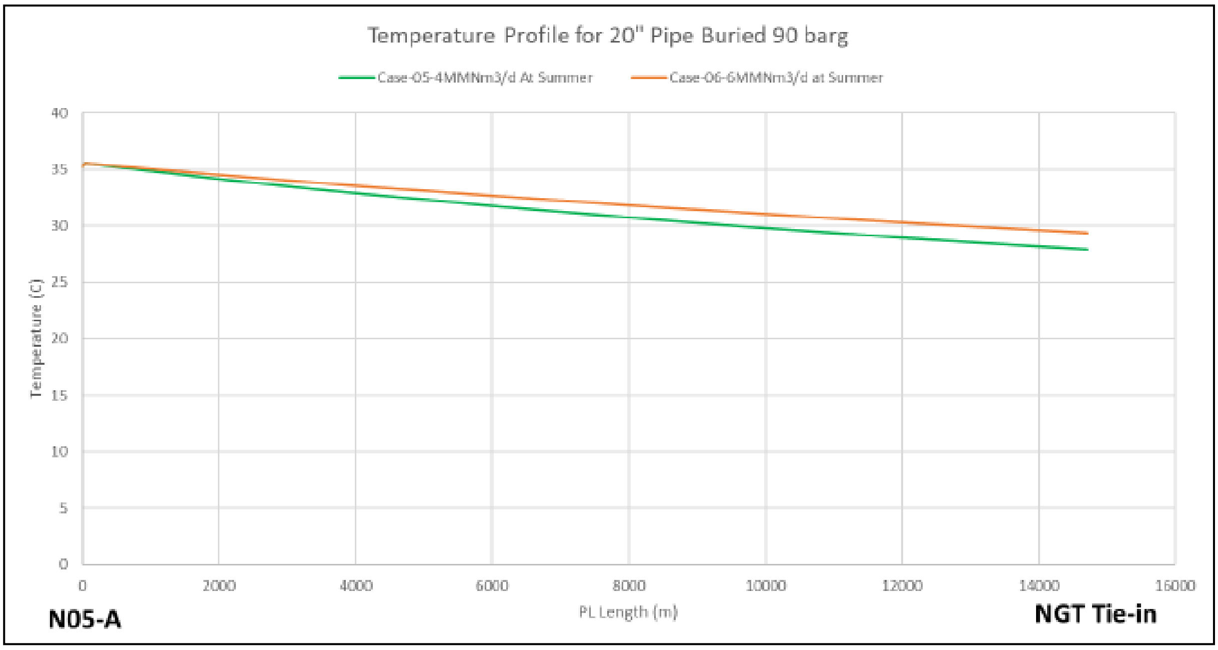


Figure 3-1 Operational thermal profile, nominal operation in summer

3.3. Coating Material Properties

Typical material properties of the coating are given in Table 3-4.

Property	Value
Anti-corrosion material type	3LPP
Anti-corrosion coating density	930 kg/m³
Anti-corrosion coating thermal conductivity	0.22 W/m°C
Anti-corrosion coating specific heat capacity	2000 J/kg°C

Table 3-4 Steel pipe coating material properties

3.4. Flange Properties

Table 3-5 presents the flange classes and main characteristics. The flange loads will be checked by using the ASME BPVC [10] flange integrity check. Note that table 3-5 is applicable to all flanges on the flowline and spool pieces.

Property	Export gas line
Flange rating	ANSI/ASME Class 1500
Flange type	RTJ Swivel / Weld Neck
Weld end thickness	20.62mm

Table 3-5 Flange properties

3.5. Environmental Data

For the design of the pipeline, environmental data has been taken from Ref. [ix] and [x]. Where Ref [ix] contains the metocean data for the platform (water depth 26 m); Ref [x] contains the Metocean data for the NGT tie-in (water depth 8 m) target box. Tables 3-6 to 3-11 present the relevant metocean data for the 1 and 100 year design conditions for the applicable locations.

The shallow water depths encountered along the pipeline route pose problems in determining the hydrodynamics loads encountered by the pipeline. Enersea has developed a calculation method based on Stokes 5th order wave theory, however in shallow waters this method is not applicable. The metocean reports [ix, x] provide a wave orbital velocity at 1 m above the sea bed, denoted as U_{1m}. For the water depth of 26 m, the Stokes theorem is at the limit of applicability and produces wave velocity approximately 10% higher than provided in the metocean report for this depth. To remain conservative, the higher velocity has been used for the location of 26 m water depth.

In order to establish environmental conditions at an intermediate pipeline location with a water depth of 17m, current and wave particle velocities have been averaged. This approach has been agreed with One-Dyas [xv].

Property	1-year return period	100-year return period
Positive surge (m) @26m	1.58	3.04
Negative surge (m)	-1.02	-1.79
LAT with respect to MSL (m)	-1.41	
HAT with respect to MSL (m)	1.31	

Table 3-6 Near platform extreme water level data [ref. II]

Return Period Depth Level	Extreme Cs [m/s] Direction [towards]								OMNI
	N	NE	E	SE	S	SW	W	NW	
1-year									
Near-surface	0.36	0.94	0.98	0.70	0.42	0.77	0.98	0.59	0.98
Mid-Depth	0.40	0.89	0.90	0.53	0.27	0.62	0.90	0.51	0.90
Near-bed	0.38	0.74	0.74	0.42	0.25	0.56	0.74	0.43	0.74
100-years									
Near-surface	0.46	1.21	1.27	0.91	0.55	1.00	1.27	0.76	1.27
Mid-Depth	0.51	1.15	1.16	0.68	0.35	0.79	1.16	0.66	1.16
Near-bed	0.49	0.95	0.96	0.55	0.32	0.72	0.96	0.55	0.96

Table 3-7- Near platform design current data [ref. II]

Return Period Direction [from]	Hs [m]	Tz [s]	Tp [s]	Cmax [m]	Hmax [m]	THmax [s]	U_{1m} [m/s]
1-year							
North	5.3	9.2	11.7	5.9	9.3	9.5	1.67
North-east	3.8	6.8	8.3	4.3	6.7	8.5	1.04
East	2.6	5.2	6.6	3.0	4.7	7.5	0.55
South-east	2.1	4.6	5.2	2.3	3.6	6.9	0.34
South	2.4	4.7	5.2	2.8	4.3	7.3	0.48
South-west	3.2	5.6	6.2	3.6	5.6	8.0	0.78
West	4.7	8.0	10.5	5.3	8.3	9.1	1.43
North-west	6.5	9.9	12.4	7.3	11.4	10.1	2.19
100-years							
North	8.1	11.5	14.3	9.1	13.8	10.8	2.73
North-east	5.9	8.1	10.4	6.6	10.0	9.7	1.84
East	4.0	5.9	8.2	4.5	6.9	8.6	1.07
South-east	3.1	4.9	6.0	3.5	5.4	7.9	0.71
South	3.7	5.0	6.0	4.2	6.4	8.4	0.95
South-west	4.9	6.4	7.3	5.5	8.3	9.1	1.43
West	7.2	9.8	12.9	8.1	12.3	10.4	2.40
North-west	9.9	12.3	14.9	11.1	16.9	11.5	3.20

Table 3-8 Near platform design wave data [ref. II]

Property	1-year return period	100-year return period
Positive surge (m) @8m	1.48	2.72
Negative surge (m)	-0.90	-1.26
LAT with respect to MSL (m)	-1.89	
HAT with respect to MSL (m)	1.61	

Table 3-9 Near tie-in extreme water level data [ref. III]

Return Period Depth Level	Extreme Cs [m/s] Direction [towards]								Omni
	N	NE	E	SE	S	SW	W	NW	
1-year									
Surface	0.31	0.52	1.04	0.51	0.27	0.50	1.04	0.59	1.04
Mid-depth	0.30	0.50	1.01	0.44	0.25	0.43	1.00	0.55	1.01
Near-bed	0.26	0.45	0.89	0.23	0.10	0.19	0.61	0.39	0.89
100-years									
Surface	0.37	0.63	1.25	0.62	0.32	0.60	1.25	0.71	1.25
Mid-depth	0.36	0.60	1.21	0.53	0.31	0.52	1.20	0.66	1.21
Near-bed	0.33	0.57	1.12	0.29	0.13	0.23	0.77	0.49	1.12

Table 3-10 Near tie-in design current data [ref. III]

Return Period Direction [from]	Hs [m]	Tz [s]	Tp [s]	Cmax [m]	Hmax [m]	THmax [s]	U_{1m} [m/s]
1-year							
North	3.6	6.2	10.3	3.3	4.8	7.5	1.2
North-east	2.2	4.9	7.7	2.0	2.9	6.5	0.6
East	1.6	3.9	5.0	1.5	2.2	5.9	0.4
South-east	1.5	3.6	3.7	1.4	2.0	5.8	0.3
South	1.4	3.5	3.9	1.3	1.9	5.7	0.3
South-west	2.0	4.1	4.5	1.9	2.7	6.3	0.5
West	3.0	5.7	10.2	2.8	4.1	7.2	0.9
North-west	3.9	6.4	12.1	3.6	5.2	7.7	1.3
100-years							
North	3.9	6.4	10.6	4.2	5.7	7.9	1.5
North-east	2.4	5.1	7.9	2.6	3.5	6.8	0.8
East	1.7	4.1	5.2	1.9	2.6	6.2	0.5
South-east	1.6	3.7	3.8	1.8	2.4	6.1	0.4
South	1.6	3.7	4.1	1.7	2.3	6.0	0.4
South-west	2.2	4.3	4.6	2.4	3.2	6.7	0.7
West	3.3	6.0	10.7	3.6	4.9	7.5	1.2
North-west	4.2	6.6	12.6	4.5	6.2	8.1	1.6

Table 3-11 Near tie-in design wave data [ref. III]

3.6. Marine Growth

The following marine growth has been assumed, in accordance with NEN 3656 [1]

From	To	Thickness	Density
+2m LAT	Seabed	50mm	1300 kg/m3

Table 3-12 Assumed marine growth properties

3.7. Geotechnical Data

Three lab result reports , Refs [xi] through [xiii], present properties of soil samples taken. These classify the soil as fine to medium sand. The soil properties are listed in Table 3-13, data has been taken from the lab reports and recommended values as per NEN3656 table H.1 ref[1] based on the soil description as presented in. A SBP data example of the north end of the proposed route is presented in figure 3-14.

Soil type	Applicable area	Submerged Unit Weight (kN/m³)	Angle of internal friction (°)
Medium sand (measured)		10.2-10.5	32.5-34.9
Medium sand	Pipe on surface	10	32.5
	Trench backfill	8.5	28
Rock dump	Crossing / Tie-in	10	40

Table 3-13 Assumed soil geotechnical properties

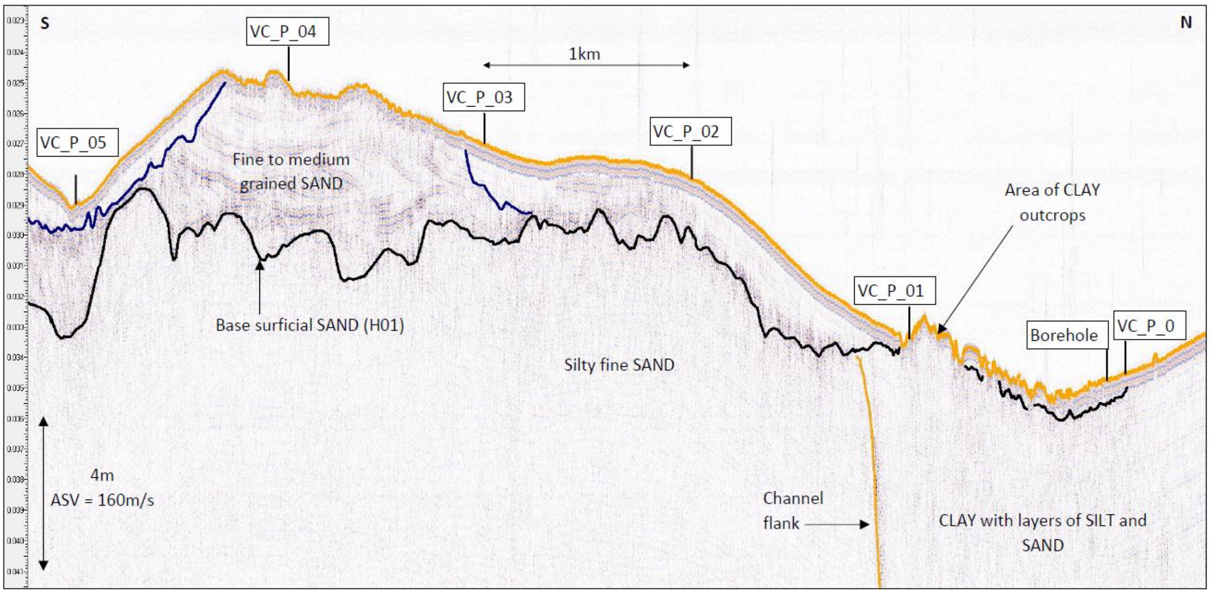


Figure 3-2 Soil profile from KP 0.0 to KP 6.0

4. Pipeline Route Data

This chapter deals with the pipeline route data describing the starting and end point of the pipeline, the used coordinate system, pipeline route coordinates and key facilities as well as the route bathymetry and contacts detected along the pipeline route. Based on this info the most optimal pipeline routing has been selected (ref. [ii].

4.1. General

The new pipeline to be installed originates at the new N05-A Platform and terminates at the NGT platform via a dedicated tie-in connection. The pipeline length is approx. 14.7 km.

An installation of the pipeline on top of the seabed has been indicated as an opportunity. The final cover height, or required concrete coating thickness will be determined based on the results of a risk assessment study [xiv], the on-bottom stability analysis [viii] and the upheaval buckling analysis.

Two pipeline/cable crossings are foreseen along the route. An overview of the field lay out is given in Figure 4-1.

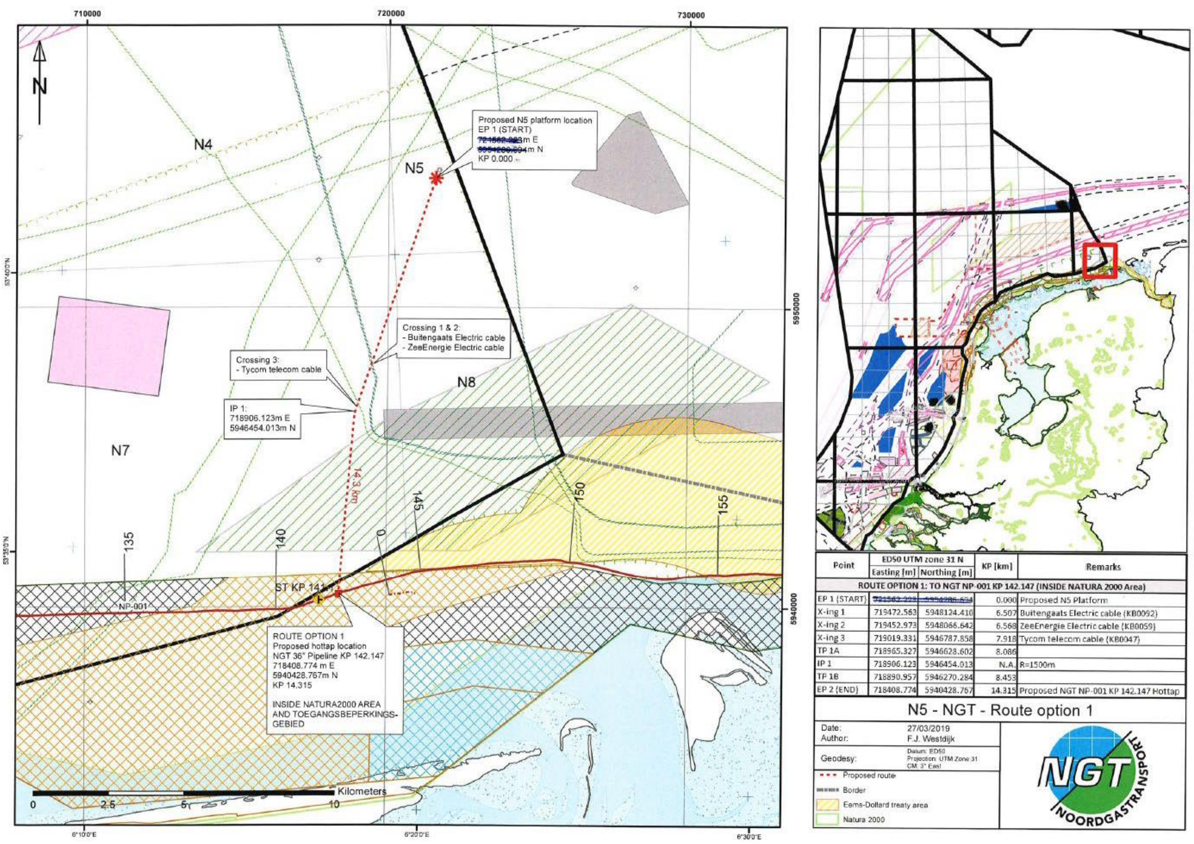


Figure 4-1 Overview N05A platform to the tie-in location

4.2. Coordinate System

The parameters of the geodetic system to be used for horizontal positions are listed in Table 4-1.

Item	Value
Datum	European Datum 1950 (ED50)
Projection	ED50 / UTM zone 31 N
Ellipsoid name	International 1924
Semi major axis	6 378 388 m
Inverse flattening	297.000
Central Meridian	03°00"00' E
Latitude of Origin	00°00"00' N
False Northing	0 mN
False Easting	500 000 mE
Scale Factor	0.9996

Table 4-1: Geodetic parameters

The vertical position is given relative to the Lowest Astronomical Tide (LAT).

4.3. Key Facility Coordinates

The following platform and tie in locations have been derived from Ref. [ii] and are presented in Table 4-2.

Item	Northing (m)	Easting (m)
N05A Platform target box	5 954 608	721 622
NGT target box	5 940 549	718 738
NGT hot tap location KP142.1	5 940 532	718 766
Water depth at N05A Platform	26 m LAT	
Water depth at NGT hot tap	9.8 m LAT	

Table 4-2 Key Facility coordinates

4.4. Bathymetry

Figure 4-3 shows the bathymetry along the surveyed flowline route. The water depths recorded during survey along the proposed N05-A platform and the NGT pipeline hottap location ranges between 9.8 m LAT and 26.4 m LAT.

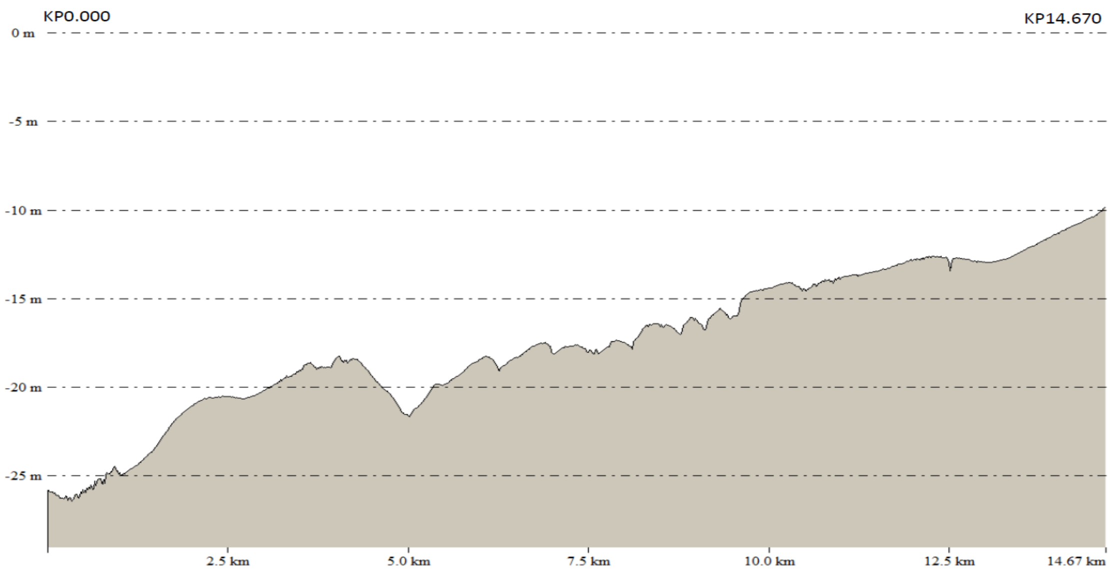


Figure 4-3 Seabed profile along pipeline route from P11-Unity Platform to Wye

4.5. Side Scan Sonar Contacts & Magnetometer Anomalies

Ref. [5] describes the seafloor sediments across the N05-A to the proposed NGT hottap location survey area to consist of a top layer of fine to coarse sand, with occasional areas of coarse sand and clay with gravel and shell fragments. Photographs taken along the proposed route show the presence of small ripples covering the majority of the seabed within the survey corridor area.

Numerous boulders and items of debris are observed in the survey area. Most of the boulders occur in the north of the survey area and coincide with areas of clay exposure.

4.5.1. Magnetometer Anomalies

A total of 241 magnetic anomalies (appendix A) were picked within the surveyed N05-A platform to the 36" NGT Tie-in and N05-A platform to Riffgat Tie-in route corridor. Most of these anomalies can be attributed to unknown identified seabed features the following seabed infrastructures are known, one (1) pipeline and four (4) cables. However, one (1) unknown linear feature.

The following existing pipelines and cable are detected:

- 36" Pipeline from L10-AR to Uithuizen
- Tycom Telecom cable
- Buitengaats Power cable
- Zeeenergie Power cable
- Norned Power cable

4.5.2. Side Scan Sonar Contacts

Eight-Hundred-Thirty (830) side scan sonar contacts were observed within the route survey. Most of the contacts are boulders located around the N05-A platform and stretching to the east side to Riffgat, besides the bolders the following contacts are found, twenty-six (26) debris items, two (2) wrecks.

4.6. Pipeline and Cable Crossings

The following crossings along the pipeline route are envisaged:

Infrastructure Name	KP	Northing (m)	Easting (m)
Buitengaats Electric cable	6.412	719 346	5 948 729
ZeeEnergie Electric cable	6.487	719 327	5 948 655
Tycom Telecom Cable Hunmanby GAP - Eemshaven	8.180	718 915	5 947 014

*) The N05A Pipeline will be connected to the NGT Pipeline with a Hot tap. This hot tap is not part of the scope of the design report.

4.7. Approach

Near the platform a T-piece will be installed including 2 ball valves for the purpose of a future pipeline connection. At the NGT tie-in location 2 ball valves and a check valve will be placed for tie-in purposes. Figures 4-4 and 4-5 present an overview of respectively the platform and the tie-in location.

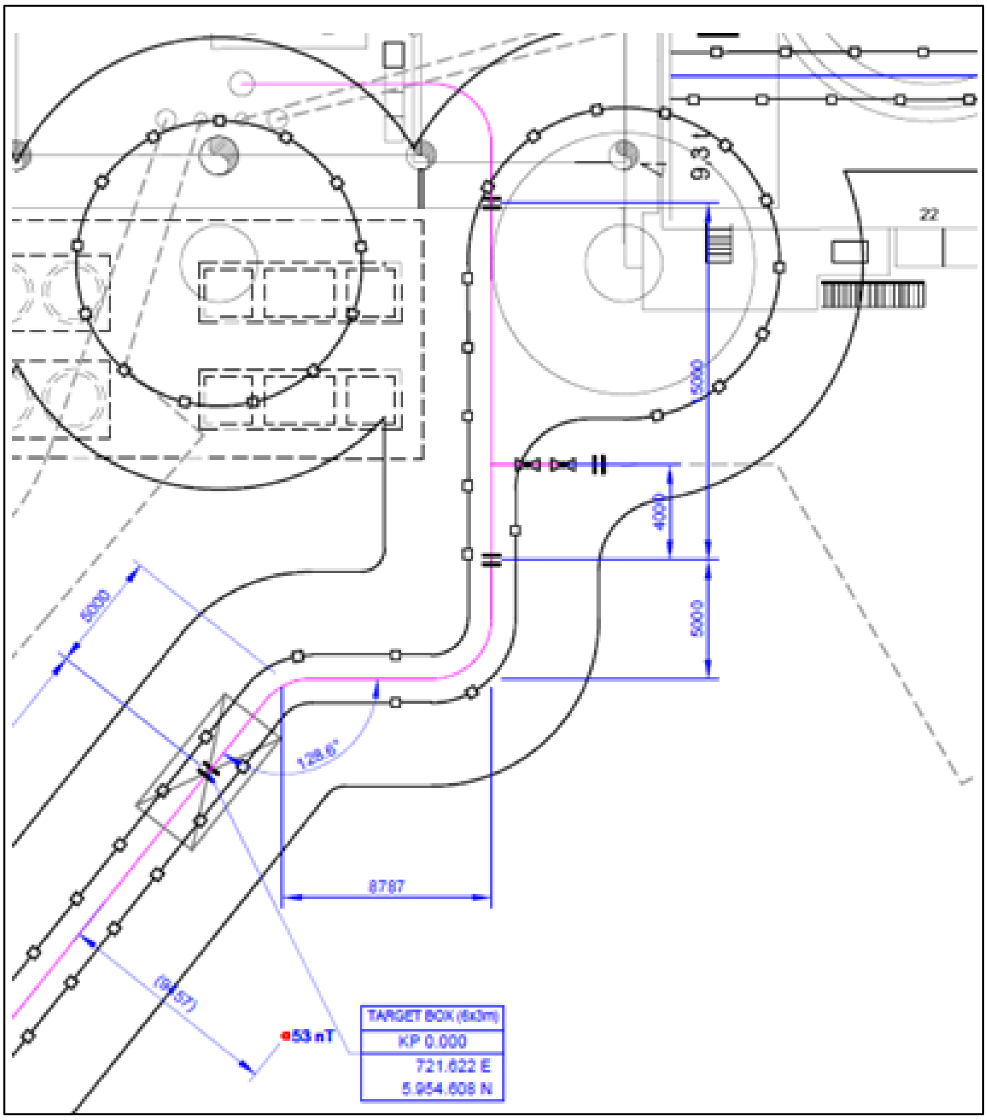


Figure 4-4 approach layout near the platform

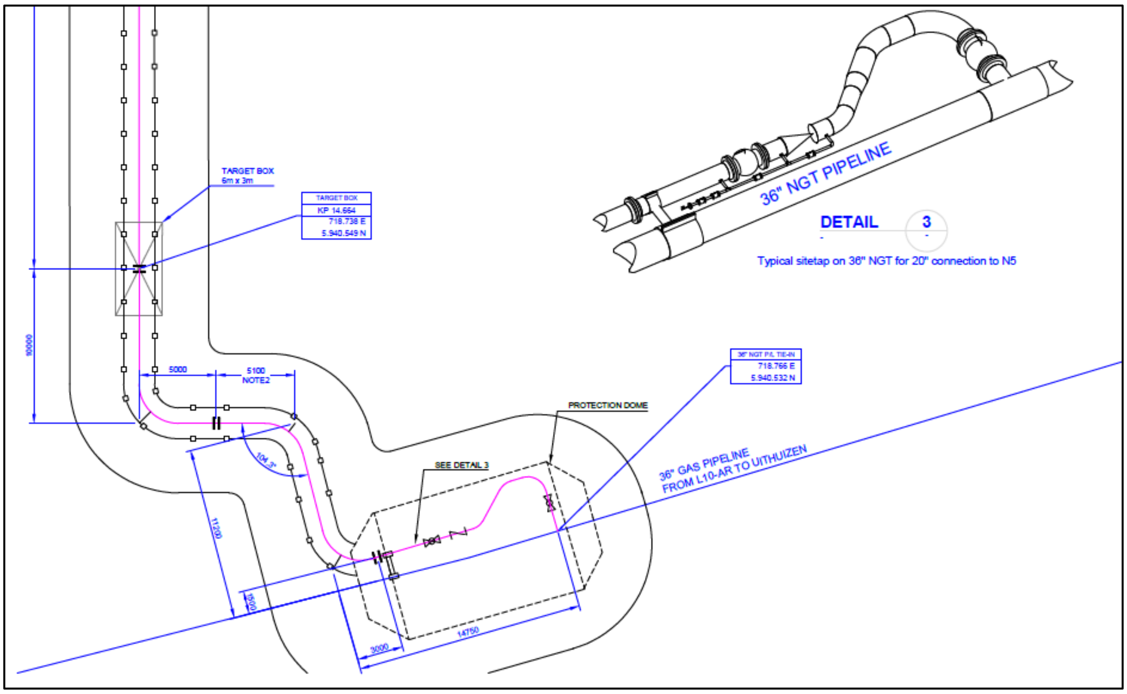


Figure 4-5 approach layout near the tie-in

5. Stress Criteria & Load Factors

5.1. Stress Criteria

Stresses in the flowline will be assessed according NEN 3656 (Ref. [1])
The analysis will account for the load history of the pipe over the design life by considering the following three load cases:

- Installation
- Hydrotest
- Operational

Considering the design cases listed above the following design loads will be considered when performing the stress analysis, see Table 5-1. The hydrodynamic loads for pipeline stability and maximum span are included via analytical calculations, see chapters 6 and 7.

Load	Installation	Hydrotest	Operation
Pressure	N/A	Hydrotest Pressure	Operational Pressure
Temperature	Seawater Temperature	Seawater Temperature	Operational Temperature
Internal Fluid	Seawater	Seawater	Product Filled
Wall Thickness	Nominal	Nominal	Nominal / Fully corroded
Hydrodynamic Loads	1-year wave + 1-year current	1-year wave + 1-year current	100/10-year wave + 10/100-year current

Table 5-1 Design loads

Calculated equivalent stresses for the various design conditions will be checked against the allowable stress values, as per NEN3656 (Ref. [1]), see Table 5-2.

Case	Load Combination As Per NEN3656 Table 3.	Limit Stress	Allowable Equivalent Stress (L360NB)
Installation	LC1	$R_{e(\theta)} / \gamma_m$	327 MPa
Hydrotest	LC4	$0.85\ (R_e + R_{e(\theta)})/\ \gamma_m$	556 MPa
Operation (Nominal / Corroded)	LC4	$0.85\ (R_e + R_{e(\theta)})/\ \gamma_m$	556 MPa

Table 5-2 Applied stress limits

Where:

Re = specified minimum yield strength at 20ºC (N/mm^2).

$R_{e(\theta)}$ = the yield strength of the material at design temperature.

γ_m = material factor (for steel 1.1).

5.2. Load Factors

All design loads applied will be factored as per the requirements of NEN 3656 (Ref. [1]), see Table 5-3.

Loads	**Load factors for load combinations (a)**								
Load combinations	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6	LC 7a	LC 7b	LC 8
Internal pressure (design pressure)	-	1.25	-	-	-	-	1.0		1.0
Internal pressure (In combination)	-	-	-	1.15	1.15	-	-	1.0	1.15
Internal pressure (max. Incidental pressure)	-	1.10	-	-	-	-	-		1.1
Temperature differences (c g)	1.0	-	-	1.10	1.10	-	1.0	1.0	-
Soil parameters (d)	-	-	(d)	(d)	(d)	-	-	Low	-
Forced deformation (e)	-	-	1.1	1.1	1.1	1.1	-		-
Own weight	1.1	-	1.1	1.1	1.1	1.1	1.0		1.0
(Possible) coating (h)	1.2	-	1.2	1.2	1.2	1.2	1.0	1.2	1.0
Pipe contents (h)	1.1	-	1.1	1.1	1.1	1.1	1.0	1.1	1.0
Installation loads (f)	1.1	-	1.10	-	-	1.1	-		-
Hydrostatic pressure	1.1	-	1.1	1.1	1.1	1.1	1.0	1.1	
Marine growth (h)	-	-	1.2	1.2	1.1	-	1.0	1.0	1.0
Hydrodynamic forces	1.1	-	1.2	1.2	1.1	1.1	1.0	1.2	1.0

(a)	If a load has a favorable influence on the considered case this will not be considered if the load is variable and for a permanent load a multiplication factor of 0.9 is applied.
(b)	The maximum incidental pressure does not need to be checked separately however must be ascertained by the pressure control system.
(c)	During calculations of stress variations caused by temperature differences the highest and lowest occurring operation temperature should be considered. The displacements loads and moments exerting on connected equipment and/or structures are to be considered based on the design temperatures i.e. the temperature difference between the installation temperature and the maximum operational temperature.
(d)	Reference is made to ref. [1] – K.4 to determine load spreading factors
(e)	Forced deformations can be caused by: settling differences trench roughness execution sacking differences deformations due to prevented thermal expansion distortions in horizontal drilling and bottom-tow installation.
(f)	Examples of installation loads are those applied during pipelay tie-ins trenching landfalls and HDD etc.
(g)	Combined with measurements.
(h)	In the stability check (BC 7b) the most unfavorable combination must be chosen. If necessary divide by the relevant factor.

Table 5-3 Load factors

A description of the load combinations is shown below;

LC 1: Installation

LC 2: Only internal pressure, operating pressure, incidental pressure

LC 3: External load with zero internal pressure

LC 4: External load with internal pressure and temperature difference

LC 5: Variable load (primarily static load, e.g., temperature changes and pressure)

LC 6: External pressure, external load and internal pressure zero

LC 7a: Incidental load (other than internal pressure)

LC 7b: Incidental load (meteorological)

LC 8: Dynamic loading

5.3. Hydrodynamic Loads

Hydrodynamic loads arise from the relative motions between pipe and seawater. They consist of drag, lift and inertia forces.

The drag force F_D is given by:

$$F_D = C_D \cdot OD_{tot} \cdot \frac{1}{2} \cdot \rho \cdot V \cdot |V|$$

Where:

C_D	=	drag force coefficient (-)
OD_{tot}	=	total diameter of coated pipe (m)
ρ	=	mass density of surrounding fluid (kg/m^3)
V	=	velocity of the fluid normal to the pipe axis (m/s)

The lift force F_L is calculated by the following equation:

$$F_L = C_L \cdot OD_{tot} \cdot \frac{1}{2} \cdot \rho \cdot V^2$$

Where:

C_L	=	lift force coefficient (-)

The inertia force F_I is determined by the following equation:

$$F_I = \rho \cdot C_I \cdot \frac{\pi}{4} \cdot OD_{tot}{}^2 \cdot a$$

Where:

C_I	=	inertia force coefficient (-)
a	=	Fluid particle acceleration (m/s^2)

The recommended values of hydrodynamic coefficients for the on-bottom stability design as a function of the embedment of the pipeline are listed in Table 5-4.

Coefficient	Pipe embedment		
	0%	**10%**	**20%**
Drag	0.70	0.63	0.53
Lift	0.90	0.90	0.81
Inertia	3.29	2.80	2.30

Table 5-4 Overview hydrodynamic coefficients

Typically, the peak hydrodynamic load is experienced just after the peak wave particle velocity, due to the additional inertia contribution. As stated in Section 3.5, wave models are not used in the shallow water depths, but only the peak velocity from the metocean report. No information on the particle acceleration is provided, however. The contribution of the inertia term is typically <10% of the drag term at peak velocity. To be conservative, a 20% margin is added to the drag term.

6. Wall Thickness Analysis

Several phenomena are to be investigated prior to finalising the selected wall thickness. Elements to be taken into account:

- pressure containment;
- on-bottom stability;
- implosion;
- progressive plastic collapse;
- local buckling;
- bar buckling;

6.1. Pressure Containment

6.1.1. Design Condition

NEN 3656, states that for every load combination the design resistance (R_d) must be greater than or equal to the loading effect (S_d) or:

$$R_d \geq S_d$$

R_d is defined as:

$$R_d = R_{e(\Theta)} / \gamma_m$$

Where:

$R_{e(\Theta)}$	=	yield strength of the material at design temperature (N/mm^2)
γ_m	=	material factor (1.1 for steel)

For load combination LC2 (internal pressure only), the equation for hoop stress can be expressed as:

$$\sigma_h = \frac{\gamma_p \cdot P_d \cdot (OD - t_{\min})}{2 \cdot t_{\min}}$$

Where:

s_h	=	hoop stress (N/mm^2)
γ_p	=	load factor as per Table 5-3 (-) => 1.25
Pd	=	design pressure (N/mm^2)
OD	=	outside diameter of steel pipe (mm)
t_{min}	=	minimum wall thickness (mm)

The selected wall thickness (t_{nom}) is then determined by:

$$t_{nom} = \left\{ \frac{t_{\min} + CA}{1 - f_{tol}} \right\}$$

Where:

CA	=	applicable corrosion Allowance (mm)
f_{tol}	=	fabrication tolerance (%)

Further to this, NEN 3656 specifies additional requirements for bends with a bending radius R_b < 10 OD, to adjust the hoop stress of straight pipe (torus effect).

$$S_h(bi) = \frac{2R_b - \frac{1}{2}OD}{2R_b - OD} \cdot S_h \quad \text{(for inside bend)}$$

$$S_h(bo) = \frac{2R_b + \frac{1}{2}OD}{2R_b + OD} \cdot S_h \quad \text{(for outside bend)}$$

6.1.2. Hydrostatic Testing

The hydrostatic testing of pipeline / riser systems has two objectives:

- verify the strength of the system
- verify that there are no leaks from the system

The test pressure, P_t, will be determined as per as per Section 10.18.3 of NEN 3656 (Ref. [1]).

$$P_{t.\min} = C_p \cdot P_d \cdot \frac{R_e}{R_{ev}}$$

Where:

C_p	=	pressure test coefficient (-) => 1.30 for gas lines; 1.25 for others
P_d	=	design operating pressure (N/mm^2)
R_e	=	minimum yield stress at 20 °C (N/mm^2)
R_{ev}	=	minimum yield stress at design temperature (N/mm^2)

The maximum hydrostatic test pressure is based on the weakest part of the pipeline/riser system to be tested. The pressure shall not exceed either $P_{t,max}$ or $P_{T,mill}$, the mill test pressure. Respectively, these are defined as:

$$P_{t.\max} = \frac{2.R_e \cdot t_{\min}}{(OD - t_{\min})}$$

$$P_{T,mill} = 0.9 \cdot \frac{2 \cdot R_e \cdot t_{nom}}{OD}$$

Where:

$$t_{nom} = \left\{ \frac{t_{\min} + CA}{1 - f_{tol}} \right\}$$

Where:

t_{nom} = nominal wall thickness (mm)

t_{min} = minimum wall thickness (mm)

CA = applicable corrosion Allowance (mm)

f_{tol} = fabrication tolerance (%)

6.1.3. Results

An overview of the results of the wall thickness calculations is given in Table 6-1.

Property	Inside 500 m	Outside 500 m
Minimum WT (mm)	11.50	10.55
Minimum WT inside bend (mm)	12.13	11.14
Minimum WT outside bend (mm)	10.97	10.07
Nominal (with corrosion allowance) minimum WT (mm)	14.50	13.55
Nominal WT inside bend (mm)	15.13	14.14
Nominal WT outside bend (mm)	13.97	13.07
Selected minimum WT	20.62	20.62
Hoop stress (MPa)	232	212
Hoop stress inside bend (MPa)	244	224
Hoop stress outside bend (MPa)	221	203
Allowable stress at design temperature (MPa)	327	327
Minimum hydrotest pressure (barg)	144	144
Maximum hydrotest pressure (barg)	281	281
Mill test pressure (barg)	263	263

Table 6-1 Overview wall thickness analysis results

Reference is made to Appendix A for the detailed calculations.

6.2. On-Bottom Stability

The aim of the stability analysis is to verify that the submerged weight of the pipeline ensures lateral stability against environmental loading.

Reference is made to report “N05A-7-10-0-70035-01 N05A On Bottom Stability Analysis Design Report” (ref. [viii]) for detailed OBS analyses.

From this report it can be seen that in order to provide absolute stability during the pipeline lifetime, in which the 100-year storm conditions are applied (non-buried pipeline), an excessively thick concrete weight coating would be required (>> 500 mm). Relaxation of the displacement criterium to allow up to 10D displacement would require a minimal concrete weight coating of over 130 mm. As the determined pipeline displacements are for a single storm only, it cannot be guaranteed that the pipeline will settle in a final position. Hence the pipeline can displace even further during a next storm, potentially causing (too) high stresses/strain.

This, in combination with shallow water depths and installation limitations, results in the recommendation to bury the pipeline.

A buried pipeline is exposed to 1-year return period conditions, but still absolute stability cannot be guaranteed. However viable designs are possible when 0.5D - 10D displacements are allowed. As the timespan between the flooded lay of the pipe and trenching thereof will be minimum, it is deemed acceptable that for a buried pipeline, no additional weight coating is applied.

6.3. Implosion

6.3.1. External Overpressure

The collapse pressure p_c causing implosion (radial instability) can be determined using:

$$(P_c - P_e)\cdot(P_c^{\,2} - P_p^{\,2}) = P_c \cdot P_e \cdot P_p \cdot 2 \cdot \delta_0 \cdot \frac{D_g}{t}$$

Where:

D_g	=	nominal diameter of pipe (mm)
P_c	=	critical external pressure for collapse (N/mm2)
P_e	=	critical external pressure for elastic deformation (N/mm^2)
P_p	=	critical external pressure for plastic deformation (N/mm^2)
P_L	=	actual external pressure (N/mm^2)
δ_0	=	initial deformation (mm)
t	=	nominal wall thickness (mm)

$$D_g = \frac{1}{2}\cdot\{OD_{nom} - (OD_{nom} - 2\cdot t_{min})\}$$

The critical external pressure for plastic deformation is calculated from:

$$P_p = \frac{2\cdot R_e \cdot t}{D_{nom}}$$

The critical external pressure for elastic deformation is calculated from:

$$P_e = \frac{2 \cdot E}{1-\nu^2} \cdot \left(\frac{t}{D_{nom}}\right)^3$$

Where:

ν	=	Poisson's ratio for elastic deformation (-) => 0.3

As a part of this the initial deformation is derived from:

$$\delta_0 = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}}$$

Where:

D_{max}	=	largest diameter of the ovalized pipe cross section
D_{min}	=	smallest diameter of the ovalized pipe cross section

The maximum allowable external pressure is defined as:

$$\gamma_{g,p} \cdot P_L \le \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$$

Where:

$\gamma_{g,p}$	=	load factor (-) => 1.05
γ_M	=	model factor (-) => 0.93
$\gamma_{m,p}$	=	material factor (-) => 1.45

6.3.2. Bending Moment

In case of a bending moment on the pipe, the moment which will cause buckling is calculated from the plastic moment of the pipe section.

$$M_c = D_{nom}{}^2 \cdot t \cdot R_e$$

The maximum allowable bending moment is defined as:

$$\gamma_{g,M} \cdot M_L \le \frac{\gamma_M \cdot M_c}{\gamma_{m,M}}$$

Where:

$\gamma_{g,M}$	=	load factor (-) => 1.1
γ_M	=	model factor (-) => 1.0
$\gamma_{m,M}$	=	material factor (-) => 1.3
M_L	=	allowable bending moment for buckling (Nm)
M_c	=	critical bending moment for buckling (Nm)

6.3.3. Combined External Pressure and Bending Moment

When external pressure exists in combination with a bending moment besides the checks above the condition for combined stresses as shown below shall be fulfilled.

$$\frac{\gamma_{g,p} \cdot P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,m} \cdot M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$$

Where:

$$n = 1 + 300 \cdot \frac{t}{D_{nom}}$$

Where:

$\gamma_{g,p}$	=	load factor for pressure (-) => 1.05
$\gamma_{g,m}$	=	load factor for bending (-) => 1.55
γ_M	=	model factor (-) => 0.93
$\gamma_{m,p}$	=	material factor for pressure (-) => 1.25
$\gamma_{m,M}$	=	material factor for bending (-) =>1.15
M_L	=	allowable bending moment for buckling (Nm)
M_c	=	critical bending moment for buckling (Nm)

6.4. Progressive Plastic Collapse

Progressive plastic deformation load cycle will lead to extreme deformation, collapse and cracks initiation through the wall.

The condition for avoiding buckle propagation is:

$$\varepsilon_{\max} = \alpha \cdot \Delta T \leq \left[\frac{R_{ev}}{E} \cdot \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_h}{R_{ev}}\right)^2} + \frac{R_e}{E}\sqrt{0.9 - \frac{3}{4}\left(\frac{\sigma_h}{R_e}\right)^2} \right]$$

Where:

α	=	coefficient of linear thermal expansion (m/ m/ ° C)
ΔT	=	temperature differential [° C] (design – installation)

Parameters have to be factored as defined in section 5.

6.5. Local Buckling

In accordance with NEN 3656, if OD / t < 55, an assessment on local buckling can generally be omitted.

For this project it would mean that a local buckling check is required for a wall thickness of minimal 9.2 mm, which will be much smaller than the anticipated wall thickness. This will be checked during detailed design.

6.6. Bar Buckling

In a free span the pipeline will be susceptible to bar buckling. Bar buckling may occur due to an effective axial compressive force (N) in the pipeline. The compressive force in an axially restrained pipeline is based on the longitudinal stress:

$$N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$$

Where:

A	=	cross sectional area of steel (mm^2)
ν	=	Poisson's ratio for elastic deformation (-) => 0.3
S_h	=	factored hoop stress (N/mm^2)
γ_t	=	load factor as given in Table 5-3 (-)
α	=	coefficient of thermal expansion (m/m/°C)
ΔT	=	pipeline temperature differential (° C) (design – installation)

The factored hoop stress (S_h) is calculated from:

$$S_h = \gamma_P \cdot \sigma_h$$

and

$$\sigma_h = \frac{P_d \cdot (OD - t_{\min})}{2 \cdot t_{\min}}$$

Where:

P_d	=	design pressure (N/mm^2)
t_{min}	=	minimum pipe wall thickness (mm)
OD	=	outside diameter of steel pipe (mm)
γ_P	=	load factor as given in Table 5-3 (-)

The buckling length is based on the Euler buckling load definition, defined in Ref. [3]. Bar buckling is avoided if the span length fulfils:

$$L \leq \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$$

Where:

L	=	allowable span length (mm)
I	=	moment of inertia (mm^4)

6.7. Results Buckling & Collapse

Appendix B contains the calculation sheet for the buckling and collapse calculations discussed in the previous sub-sections. The results are also summarized in Table 6-3 (8m WD), Table 6-4 (17m WD) and Table 6-5 (26m WD).

Property	Install (flooded	Hydrotest	Operation
Material	L360		
Temperature (deg. C)	15	15	65
Yield at temperature (N/mm2)	360	360	360
Pressure (barg)	2	144	111
Content density (kg/m3)	1025	1025	96
Storm surge (m)	-0.14		-0.78
Hmax (m)	5.2		6.2
Tass (s)	7.7		8.1
Current velocity @ 1m ASB (m/s)	0.89		1.12
Collapse – external pressure only			
Actual external pressure (MPa)	0.19		
Allowable external pressure (MPa)	16.0		
Check	OK		
Collapse – bending moment only			
Maximum allowable bending moment (kNm)	1256		
Collapse – external pressure & bending moment			
Maximum allowable bending moment (kNm)	1001		1001
Maximum span length collapse (m)	62.6	62.6	76.7
Progressive plastic collapse			
Actual strain (-)	0.0001	0.0001	0.0005
Allowable strain (-)	0.0033	0.0028	0.0030
Check	OK	OK	OK
Local buckling			
OD/t ratio	23.9		
Allowable ratio	55		
Check	OK		
Bar buckling			
Maximum span length (m)	93.1	- (No compres- sive force)	61.7

Table 6-3 Buckling & Collapse analysis - result summary – 8 m water depth

Property	Install (flooded	Hydrotest	Operation
Material	L360		
Temperature (deg. C)	15	15	65
Yield at temperature (N/mm2)	360	360	360
Pressure (barg)	2	144	111
Content density (kg/m3)	1025	1025	96
Storm surge (m)	-0.58		-1.29
Hmax (m)	8.3		11.55
Tass (s)	8.9		9.8
Current velocity @ 1m ASB (m/s)	0.82		1.04
Collapse – external pressure only			
Actual external pressure (MPa)	0.30		
Allowable external pressure (MPa)	16.0		
Check	OK		
Collapse – bending moment only			
Maximum allowable bending moment (kNm)	1256		
Collapse – external pressure & bending moment			
Maximum allowable bending moment (kNm)	1000		1000
Maximum span length collapse (m)	59.2	59.2	53.3
Progressive plastic collapse			
Actual strain (-)	0.0001	0.0001	0.0005
Allowable strain (-)	0.0033	0.0028	0.0030
Check	OK	OK	OK
Local buckling			
OD/t ratio	23.9		
Allowable ratio	55		
Check	OK		
Bar buckling			
Maximum span length (m)	93.1	- (No compres-sive force)	61.7

Table 6-4 Buckling & Collapse analysis - result summary – 17 m water depth

Property	Install (flooded	Hydrotest	Operation
Material	L360		
Temperature (deg. C)	15	15	65
Yield at temperature (N/mm2)	360	360	360
Pressure (barg)	2	144	111
Content density (kg/m3)	1025	1025	96
Storm surge (m)	-1.02		-1.79
Hmax (m)	11.4		16.9
Tass (s)	10.1		11.5
Current velocity @ 2m ASB (m/s)	0.74		0.96
Collapse – external pressure only			
Actual external pressure (MPa)	0.42		
Allowable external pressure (MPa)	16.0		
Check	OK		
Collapse – bending moment only			
Maximum allowable bending moment (kNm)	1256		
Collapse – external pressure & bending moment			
Maximum allowable bending moment (kNm)	999.4		999.4
Maximum span length collapse (m)	56.0	56.0	43.8
Progressive plastic collapse			
Actual strain (-)	0.0001	0.0001	0.0005
Allowable strain (-)	0.0033	0.0028	0.0030
Check	OK	OK	OK
Local buckling			
OD/t ratio	23.9		
Allowable ratio	55		
Check	OK		
Bar buckling			
Maximum span length (m)	93.1	- (No compres-sive force)	61.7

Table 6-5 Buckling & Collapse analysis - result summary – 26 m water depth

7. Free Span Analysis

Spanning of a pipeline on the seabed causes forces and stresses in the pipe. The criterion for accepting a pipeline configuration is that the pipe should not be subjected to over-stressing, nor to excessive dynamic loading because of resonant oscillations of the pipe caused by the vortex shedding phenomenon during installation, testing and throughout its operating life.

The pipeline span assessment includes the following items:

- Static span analysis
- Dynamic span analysis.

The static analysis concerns the determination of the pipe stresses under functional- and static environmental loads for a given span length.

The dynamic span analysis is based on criteria for prevention of vortex induced vibrations (VIV) as outlined in NEN 3656 considering both current- and wave induced velocities.

In addition, operational limits of the trenching equipment, limits the span gap (distance between the pipe and the seabed).

Although the pipeline will be buried below the seabed prior to its operation, the pipeline must be checked for spanning for the period between installation and burial.

In the analysis, along with the seabed topography, both functional and environmental loads are taken into consideration to check pipeline structural integrity under the considered load cases.

7.1. Static Span

Combining hoop, longitudinal and bending stresses in the pipeline, which shall satisfy criteria for equivalent stresses, gives the maximum allowable static span lengths. Checks are to be made for the installation, hydro test and operational load case.

The maximum bending moment is calculated from the (vector) combination of the pipelines' own weight and hydrodynamic forces for the maximum wave condition:

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Where:

γ_W	=	load factor as per Table 5-3 (-)
γ_H	=	load factor as per Table 5-3 (-)

End fixity of an actual span is commonly assumed between fixed - fixed and fixed – pinned and the bending moment (M) calculated from:

$$M = \frac{q \cdot L^2}{10}$$

Where:

L	=	Maximum allowable span length [m]

The maximum allowable bending moment (M_{all}) is given by:

$$M_{all} = \frac{2 \cdot I \cdot \sigma_b}{OD}$$

Where:

I	=	moment of inertia (m^4)
OD	=	pipeline outside diameter (m)
s_b	=	maximum allowable bending stress

The maximum allowable static span can then be determined by:

$$L\max = \sqrt{\frac{20 \cdot \sigma_b \cdot I}{OD \cdot q}}$$

The maximum allowable span length follows from the condition that the equivalent stress (S_e) from the load combination satisfies the following conditions:

For the operational and hydrotest cases:

$$S_e \leq 0.85 \times (R_e + R_{ev}) / \gamma_m$$

For the installation case:

$$S_e \leq R_e / \gamma_m$$

Where:

R_e	=	minimum yield stress at 20 °C (N/mm^2)
R_{ev}	=	minimum yield stress at design temperature (N/mm^2)
γ_m	=	material factor (-) => 1.1

7.1.1. Load Cases

The maximum static span will be determined for the load cases, and considering the environmental load return periods, as detailed in Table 7-1:

Condition	Wave Height Return Period	Current velocity Return Period
Installation	$H_{max,1yr}$	1 yr
Hydrotest	$H_{max,1yr}$	1 yr
Operational,1	$H_{max,100yr}$	10 yr
Operational,2	$H_{max,10yr}$	100 yr

Table 7-1 Load Cases for Span Assessment

7.1.2. Results

Tables 7-2 thru 7-5 show the results for the maximum allowable static span lengths during installation, hydro-test and operational phase. The calculation can be found in Appendix C.

7.1.2.1. Flooded installation

Property	Unrestrained pipe		Restrained pipe	
	Tension	Compression	Tension	Compression
Hoop stress (MPa)	2.9	2.9	2.9	2.9
Max. longitudinal stress (MPa)	328.7	-325.8	328.7	-325.8
Longitudinal hoop stress (MPa)	1.2	1.2	0.9	0.9
Thermal expansion stress (MPa)	N/A	N/A	-26.8	-26.8
Max. allowable bending stress (MPa)	327.3	-327.1	327.3	-299.9
Max. allowable span (m) – 8 m WD	69.3	69.3	69.3	66.3
Max. allowable span (m) – 17 m WD	65.9	65.9	65.9	63.1
Max. allowable span (m) – 26 m WD	62.8	62.7	62.8	60.1

Table 7-2 Maximum span for flooded pipe

7.1.2.2. Hydrotest

Property	Unrestrained pipe		Restrained pipe	
	Tension	Compression	Tension	Compression
Hoop stress (MPa)	249.7	249.7	249.7	249.7
Max. longitudinal stress (MPa)	637.5	-387.8	637.5	-387.8
Longitudinal hoop stress (MPa)	85.8	85.8	74.9	74.9
Thermal expansion stress (MPa)	N/A	N/A	-29.5	-29.5
Max. allowable bending stress (MPa)	551.6	-473.6	556.4	-433.2
Max. allowable span (m) – 8 m WD	89.3	82.6	89.7	79.0
Max. allowable span (m) – 17 m WD	84.4	78.2	84.8	74.8
Max. allowable span (m) – 26 m WD	79.9	74.2	80.3	70.9

Table 7-3 Maximum span during hydrotest

7.1.2.3. Operation LC1

Property	Unrestrained pipe		Restrained pipe	
	Tension	Compression	Tension	Compression
Hoop stress (MPa)	191.8	191.8	191.8	191.8
Max. longitudinal stress (MPa)	626.9	-435.1	626.9	-435.1
Longitudinal hoop stress (MPa)	66.2	66.2	57.6	57.6
Thermal expansion stress (MPa)	N/A	N/A	-123.3	123.3
Max. allowable bending stress (MPa)	556.4	-501.2	556.4	-369.4
Max. allowable span (m) – 8 m WD	112.2	106.4	112.2	91.3
Max. allowable span (m) – 17 m WD	75.4	71.5	75.4	61.4
Max. allowable span (m) – 26 m WD	63.9	60.7	63.9	52.1

Table 7-4 Maximum span for Load Case 1

7.1.2.4. Operation LC2

Property	Unrestrained pipe		Restrained pipe	
	Tension	Compression	Tension	Compression
Hoop stress (MPa)	191.8	191.8	191.8	191.8
Max. longitudinal stress (MPa)	626.9	-435.1	626.9	-435.1
Longitudinal hoop stress (MPa)	66.2	66.2	57.6	57.6
Thermal expansion stress (MPa)	N/A	N/A	-123.3	123.3
Max. allowable bending stress (MPa)	556.4	-501.2	556.4	-369.4
Max. allowable span (m) – 8 m WD	112.4	106.5	112.4	91.5
Max. allowable span (m) – 17 m WD	84.3	80.0	84.3	68.7
Max. allowable span (m) – 26 m WD	73.6	70.0	73.6	60.0

Table 7-5 Maximum span for Load Case 2

7.2. Dynamic Span

Flow of water particles induced by currents and waves perpendicular to a spanning pipeline or riser span can lead to vortices being shed. This will disrupt the flow around the pipe and thereby potentially cause periodic loads on the pipeline or riser, also known as Vortex Induced Vibration (VIV).

The natural frequency of a span being close to the vortex shedding frequency can result in a resonant oscillation, possibly resulting in fatigue failure of the pipeline or riser.

The oscillations of the span may occur in two directions:

- in line with the flow (parallel to the flow direction of the water particles)
- in cross flow direction (perpendicular to the flow direction of the water particles)

When assessing VIV, the span should be confirmed to be within acceptable limits set by either avoidance of VIV or an acceptable fatigue life for both the installation and operational condition.

Relevant dimensionless parameters governing the VIV phenomenon are the reduced velocity (V_r) and stability parameter (K_s).

The reduced velocity (V_r) parameter is defined by:

$$V_r = \frac{V_s}{f_{n \cdot OD_{tot}}}$$

Where,

V_s	=	water particle velocity due to current and significant wave (m/s)
f_n	=	1st natural frequency of the pipe span (1/s)
OD_{tot}		total outside diameter of the pipe (m)

The 1st natural frequency can be calculated from:

$$f_n = \frac{a}{2\pi} \cdot \sqrt{\frac{E \cdot I}{m_e \cdot L^4}}$$

Where,

a	=	frequency factor (-) => 15.4 for a fixed-pinned beam, which is used for the pipe
E	=	Young’s modulus (N/m^2)
I	=	moment of inertia (m^4)
L	=	length of span in pipeline / riser (m)

The stability parameter (K_s) is defined by:

$$K_s = \frac{2 \cdot m_e \cdot \delta}{\rho_{sw} \cdot OD_{tot}^2}$$

Where,

m_e	=	effective mass of pipe (kg/m)
ρ_{sw}	=	density seawater (kg/m^3)
δ	=	logarithmic decrement of damping (-) => δ = 0.126 for steel

The effective mass of the pipe can be calculated as:

$$m_e = m + \pi/_4 \cdot C_M \cdot \rho_{sw} \cdot OD_{tot}{}^2$$

Where,

m	=	Pipeline / riser mass (kg/m)
Cm	=	added mass coefficient (-)

NEN 3656 states that In-line oscillations will occur if $K_s \leq 1.8$ and cross flow oscillations will occur if $K_s \leq 16$.

7.2.1. In-line VIV

NEN 3656 furthermore states that in-line oscillations of the span occur if the reduced velocity is within the range of: $1.0 \leq Vr \leq 3.5$

Vortices around a spanning pipe occur in a relatively steady state environment. The wave induced velocity varies from a maximum at t=0, to zero at t=1/4*Twave. Furthermore, the system does not respond instantaneously to the applied forcing. To ignore the wave induced velocity in assessing the allowable dynamic span length would be too optimistic, to account for the maximum induced value would be too conservative, therefore reference is made to DNV-RP-F105. “Free Spanning Pipelines.” (ref. [3]).

According to Ref. [3], fatigue damage due to in-line VIV can be neglected if the current flow velocity ratio α, as defined by the equation below is smaller than 0.5. In the domain 0.5< α<0.8, in-line VIV is described as ‘reduced’ and requires additional work in determining the response amplitude. This additional work is left for the detail design phase.

$$\alpha = \frac{v_{cur}}{v_{cur} + v_{wave}}$$

Where,

v_{cur}	=	Particle velocity due to current [m/s]
v_{wave}	=	Particle velocity due to waves [m/s]

7.2.2. Cross-flow VIV

The occurrence of cross flow oscillations depends on the magnitude of the Reynolds number, Re, and the reduced velocity as given in Figure 7-1.

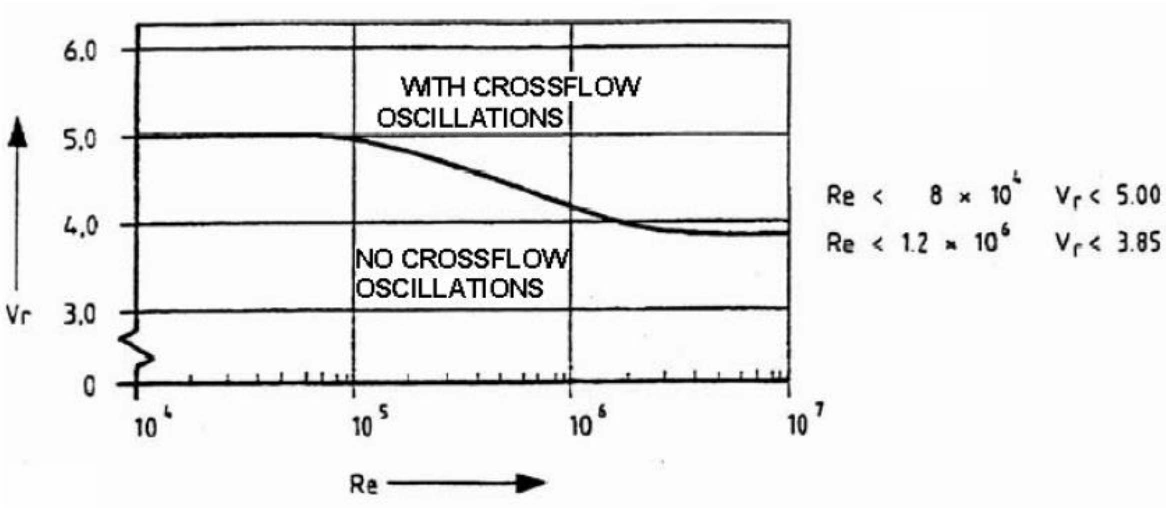


Figure 7-1 Reduced velocity for cross flow oscillations

$$\mathrm{Re} = \frac{\mathrm{v} \cdot OD_{tot}}{\nu}$$

Where,

v	=	particle velocity (m/s)
OD_{tot}	=	pipeline outside diameter (m)
n	=	Kinematic viscosity water (m^2/s) => 1,307 x 10^{-6} (at 10 °C)

7.2.3. Results

The results for the VIV analyses are presented in Tables 7-6 through 7-8. Reference is made to appendix C for more detailed calculations.

In-line VIV:

Property	Installation (flooded)	Hydrotest	Operation LC1	Operation LC2
8m WD - Wave hor. particle velocity (m/s)	1.3	1.3	1.6	1.5
8m WD - Current hor. particle velocity (m/s)	0.71	0.71	0.79	0.81
8m WD - Current velocity ratio (-)	0.35	0.35	0.35	0.37
17m WD - Wave hor. particle velocity (m/s)	1.33	1.33	2.08	1.76
17m WD - Current hor. particle velocity (m/s)	0.65	0.65	0.73	0.83
17m WD - Current velocity ratio (-)	0.33	0.33	0.26	0.32
26m WD - Wave hor. particle velocity (m/s)	1.35	1.35	2.56	2.01
26m WD - Current hor. particle velocity (m/s)	0.53	0.53	0.60	0.69
26m WD - Current velocity ratio (-)	0.28	0.28	0.19	0.26

Table 7-6 Current velocity ratio per load case

The current flow velocity ratio (α) is <0.5 for all load cases. Below this ratio, in-line VIV due to vortex shedding becomes negligible (DNV-RP-F105, Ref [3]). In the limit of $\alpha = 0.5$, the acceptable span is determined below:

Property	Installation (flooded)	Hydrotest	Operation LC1	Operation LC2
Effective mass (kg/m)	682.9	682.9	522.7	522.7
Stability parameter (-)	0.63	0.63	0.49	0.49
Reduced velocity limit (-)	1	1	1	1
Outer P/L diameter (mm)	514	514	514	514
8m WD				
Wave hor. particle velocity (m/s)	0.71	0.71	0.79	0.81
Current hor. particle velocity (m/s)	0.71	0.71	0.79	0.81
Current velocity ratio (-)	0.5	0.5	0.5	0.5
Span frequency (1/s)	2.75	2.75	3.09	3.46
Allowable span length (m)	21.9	21.9	22.1	20.9
17m WD				
Wave hor. particle velocity (m/s)	0.65	0.65	0.73	0.83
Current hor. particle velocity (m/s)	0.65	0.65	0.73	0.83
Current velocity ratio (-)	0.5	0.5	0.5	0.5
Span frequency (1/s)	2.52	2.52	2.84	3.21
Allowable span length (m)	22.9	22.9	23.0	21.6
26m WD				
Wave hor. particle velocity (m/s)	0.53	0.53	0.60	0.69
Current hor. particle velocity (m/s)	0.53	0.53	0.60	0.69
Current velocity ratio (-)	0.5	0.5	0.5	0.5
Span frequency (1/s)	2.07	2.07	2.35	2.69
Allowable span length (m)	25.2	25.2	25.3	23.7

Table 7-7 Allowable span due to in-line VIV

There is relatively little difference between the allowable span in the various conditions. This is because the VIV phenomenon is governed by the steady current, which is of similar magnitude at all locations. The selected limit of current flow velocity ratio, α=0.5, is also a significant factor. If this is increased to α=0.6, the allowable span (in-line VIV) for installation condition at 26m water depth is increased from 25.2m to 27.6m. Selecting a higher current flow velocity ratio requires that the pipeline amplitude response is further investigated, this is left to the detail design phase.

Cross flow VIV:

Property	Installation (flooded)	Hydrotest	Operation LC1	Operation LC2
8m WD				
Wave hor. particle velocity (m/s)	1.3	1.3	1.6	1.5
Current hor. particle velocity (m/s)	0.71	0.71	0.79	0.81
Reynolds nr. (-)	$2.07 * 10^6$	$2.07 * 10^6$	$2.47 * 10^6$	$2.46 * 10^6$
Reduced velocity limit (-)	3.85	3.85	3.85	3.85
Span frequency (1/s)	1.01	1.01	1.21	1.21
Allowable span length (m)	36.0	36.0	35.3	35.3
17m WD				
Wave hor. particle velocity (m/s)	1.33	1.33	2.08	1.76
Current hor. particle velocity (m/s)	0.65	0.65	0.73	0.83
Reynolds nr. (-)	$2.03 * 10^6$	$2.03 * 10^6$	$2.90 * 10^6$	$2.66 * 10^6$
Reduced velocity limit (-)	3.85	3.85	3.85	3.85
Span frequency (1/s)	1.00	1.00	1.42	1.30
Allowable span length (m)	36.4	36.4	32.6	34.0
26mWD				
Wave hor. particle velocity (m/s)	1.35	1.35	2.56	2.01
Current hor. particle velocity (m/s)	0.53	0.53	0.60	0.69
Reynolds nr. (-)	$1.94 * 10^6$	$1.94 * 10^6$	$3.26 * 10^6$	$2.78 * 10^6$
Reduced velocity limit (-)	3.85	3.85	3.85	3.85
Span frequency (1/s)	0.95	0.95	1.60	1.36
Allowable span length (m)	37.2	37.2	30.7	33.2

Table 7-7 Allowable span due to cross-flow VIV

8. Upheaval Buckling – Analytical

Buried pipelines exposed to compressive effective axial forces may get unstable beyond its anchor point and move vertically out of the seabed if the cover has insufficient resistance. An out-of-straightness configuration will result in forces acting on the cover, perpendicular to the pipeline. In case these vertical forces exceed the cover resistance the pipeline will buckle upwards.

The relation between minimum required cover height and the imperfection height (out-of-straightness) will be established in accordance with ref. [11].

Parameters used in the assessment of upheaval buckling are the dimensionless imperfection length parameter (Φ_L):

$$\Phi_L = L \cdot \sqrt{\frac{N_e}{EI}}$$

Where:

L	=	exposure length (m)
N_e	=	effective axial compressive force (N)
EI	=	bending stiffness (N m^2)

And the dimensionless maximum download parameter (Φ_w):

$$\Phi_w = \frac{w \cdot E \cdot I}{\Delta_{calc} \cdot N_e^{\,2}}$$

Where:

w	=	required download [N/m]
Δ_{calc}	=	imperfection height [m]

Depending on the Φ_L value the required download is derived from Φ_w in accordance with:

$$\Phi_w = 0.0646 \quad \text{for} \quad \Phi_L < 4.49$$

$$\Phi_w = \frac{5.68}{\phi_L^{\,2}} - \frac{88.35}{\phi_L^{\,4}} \quad \text{for} \quad 4.49 < \Phi_L < 8.06$$

$$\Phi_w = \frac{9.6}{\phi_L^{\,2}} - \frac{343}{\phi_L^{\,4}} \quad \text{for} \quad \Phi_L > 8.06$$

In cohesionless soils the uplift resistance (q) due to the cover of the pipe can be calculated from:

$$q = \gamma \cdot H \cdot OD \cdot \left(1 + f \cdot \frac{H}{OD}\right)$$

Where:

γ	=	effective under water weight of soil (N/m^3)
H	=	depth of cover (m)
OD	=	outside diameter of pipe (m)
f	=	uplift coefficient 0.5 for dense material 0.1 for loose material

The calculated required download (w) shall be smaller than the actual combination of the submerged weight and uplift resistance of the pipeline.

The simplified method from Reference [11] is conservative, in that it does not model a number of mitigating factors such as:

- The finite axial stiffness of the pipeline, which determines how rapidly the axial force diminishes as the pipeline moves upwards
- The pipeline resistance to axial movement through the soil determines how far the pipeline can slide towards a developing buckle.

Both the above factors may cause progressive upheaval buckling, as predicted by the analysis method in Reference [11], not to occur.

Further, the sinusoidal imperfection profile assumed in the model is envisaged to yield conservative download requirements.

8.1. Results

The results are presented as the minimum safe length for a given imperfection height and cover height, at the maximum operational temperature of 43°C and operational pressure of 95 barg. An ‘x’ denotes that there is no risk of upheaval buckling for the given condition. An excerpt of the calculations is presented in Appendix D.

Minimum required Imperfection Length (m)		**Cover Height to TOP [m]**													
		1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Available Download, q [N/m]		9929	9232	8553	7889	7243	6613	6000	5403	4823	4260	3714	3184	2671	2174
Imperfection Height [m]	0.05	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.15	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.2	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.25	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.3	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	0.35	x	x	x	x	x	x	x	x	x	x	x	x	x	42.6
	0.4	x	x	x	x	x	x	x	x	x	x	x	x	x	50.9
	0.45	x	x	x	x	x	x	x	x	x	x	x	x	46.3	56.3
	0.5	x	x	x	x	x	x	x	x	x	x	x	x	51.8	70.5
	0.55	x	x	x	x	x	x	x	x	x	x	x	47.7	56.0	78.0
	0.6	x	x	x	x	x	x	x	x	x	x	43.0	52.1	68.2	84.0
	0.65	x	x	x	x	x	x	x	x	x	x	48.4	55.7	75.2	89.2
	0.7	x	x	x	x	x	x	x	x	x	44.5	52.1	65.4	80.5	94.0
	0.75	x	x	x	x	x	x	x	x	x	48.7	55.2	72.6	85.1	98.5
	0.8	x	x	x	x	x	x	x	x	45.2	51.9	58.0	77.6	89.4	>100
	0.85	x	x	x	x	x	x	x	x	48.8	54.6	70.1	81.8	93.3	>100
	0.9	x	x	x	x	x	x	x	45.5	51.6	57.1	74.9	85.6	97.0	>100
	0.95	x	x	x	x	x	x	x	48.7	54.1	67.3	78.8	89.1	>100	>100
	1	x	x	x	x	x	x	45.6	51.2	56.3	72.3	82.4	92.4	>100	>100

Table 8-1 Out of straightness table

9. Bottom Roughness Analysis

9.1. General

The pipeline route experiences significant undulations in the sea bed, which may create free spans of the pipeline. In order to assess if the pipeline spans are greater than allowed in the time between installation and burial, a bottom roughness analysis. A FEA model is created which incorporates the surveyed sea floor profile, the interaction between pipe and sea floor, and the structural behaviour of the pipeline.

The finite element calculation is carried out using industry proven software package ANSYS. The analysis is at this stage of the design is limited to identifying locations with more than critical span length between installation and burial, no modifications to the sea floor are determined.

The pipeline will be modelled by ANSYS' PIPE288 element. This is a 3D pipe element consisting of 3 'layers': an internal layer to account for the weight of the internal fluid, a structural layer used for the structural calculations, and an outer layer to account for the coating. Additionally, the buoyancy of the displaced seawater is accounted for.

The pipeline is modelled with an element length of 1 m and accounts for undulations in the vertical direction. Pipe-soil interaction is simulated using three independent non-linear spring elements attached to each pipe element. The springs represent the soil frictional resistance in the axial and lateral directions and the soils bearing capacity in the vertical direction.

Seabed roughness will be simulated by displacing the vertical springs representing the soil bearing capacity to the correct depth based on the bathymetric data and allowing the pipe to move and rest on the vertical springs.

When the support force of a vertical spring is 0, a free span is identified. Similar succeeding points indicate a larger span. The length of the free span is determined by subtracting the coordinates of the beginning of the span from the coordinates of the span end. Based on the acceptable spans identified in this document, the locations where spans are larger than the critical span are found and reported.

9.2. Definition of Soil Springs

The characteristics of the springs which simulate the pipe-soil interaction are defined through non-linear force-deflection curves. These force-deflection curves describe the frictional restraint provided by the soil to the pipeline in axial, lateral and vertical direction.

Axial and lateral restraint for the unburied pipeline is included as Coulomb friction. The amount of restraint per length of pipeline depends on the friction coefficient and the submerged weight of the pipeline. A friction coefficient of 0.6 was used in both directions, this excludes the effect of soil berms created by lateral movement of the pipeline. In accordance with DNV-RP-F109, the friction coefficient of a pipe on sand is set to 0.6. The maximum friction force is only reached when a nominal displacement has been reached, the mobilization displacement. In the present analysis, mobilization displacement is set to 5 mm. A third point in the spring reaction diagram is set at a displacement of 1m with a reaction force of 1.001 time the maximum friction force, this prevents extrapolation of the first section of the spring slope.

Vertical support follows from the bearing capacity of the idealized 2D strip foundation theory. A touchdown lay factor k_{lay} of 2 has been considered during the installation load case, according to DNV-RP-F114, ref [12]. The 'installation' type supports do not provide resistance against upwards movement of the pipe.

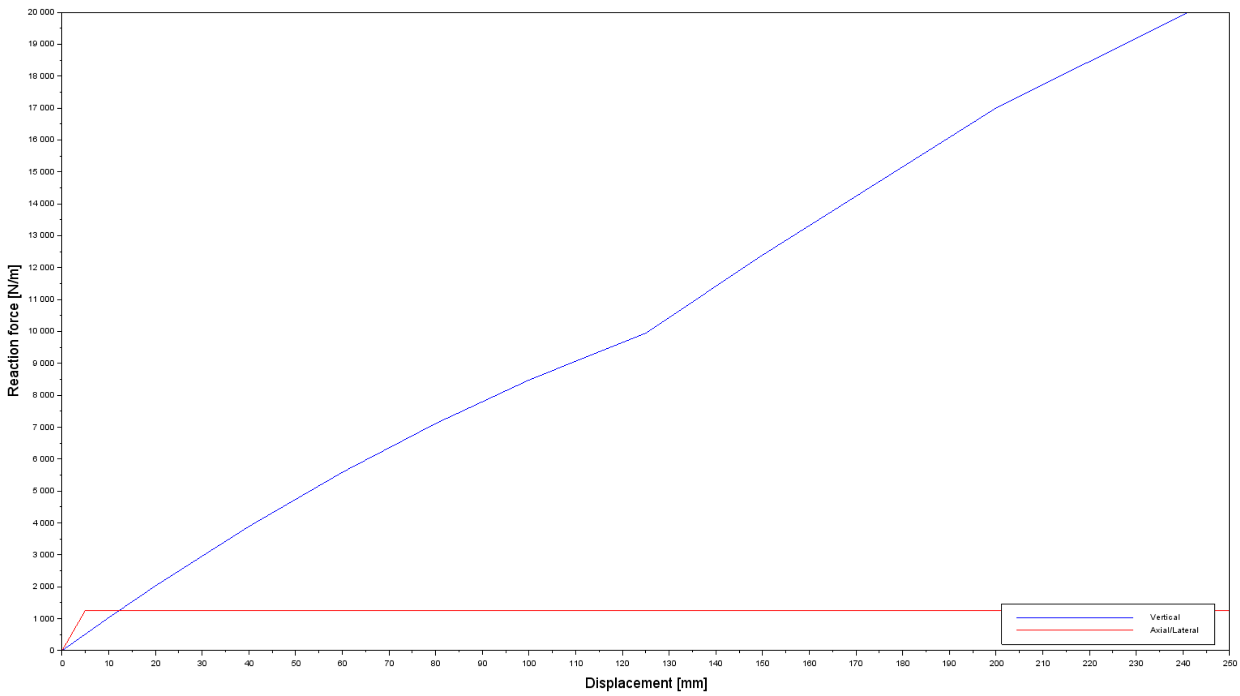


Figure 8-1 Vertical and axial support

9.3. Results

The result of pipeline installation on the as-surveyed sea bed profile is given in Table 8-1, and Figures 8-2 through 8-4. Three (3) spans longer than 20 m were found, all in the first kilometre of the pipeline. If the critical span criterium is set as 25m between KP0 and KP2, 23m between KP2 and KP10, and 22 m from KP10 to the end of the pipeline, only the span of 27 m between KP0.406-0.433 violates these criteria. These criteria are based on on the 1-year environmental conditions, for the installation and hydrotest condition.

Table 8-1 Overview largest spans

Span #	Start of span [m]	End of span [m]	Span length [m]
1	406	433	27
2	455	478	23
3	707	729	22

The design criterion of span length is only marginally exceeded, and as noted in Section 7.2, additional investigation in the dynamic response of the pipeline could extend the allowable span to more than 27m. This would remove the need for sea bed modifications. The additional investigations are left for the detail design phase of the pipeline.

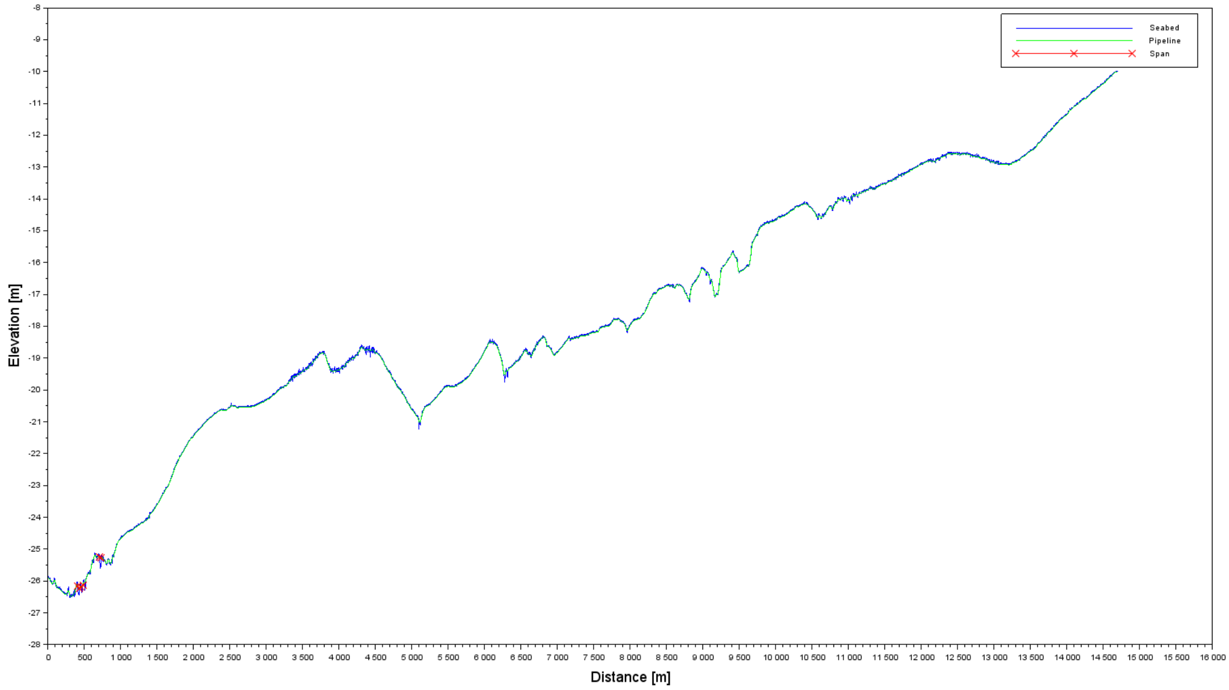


Figure 8-2 Pipeline on sea floor, complete route

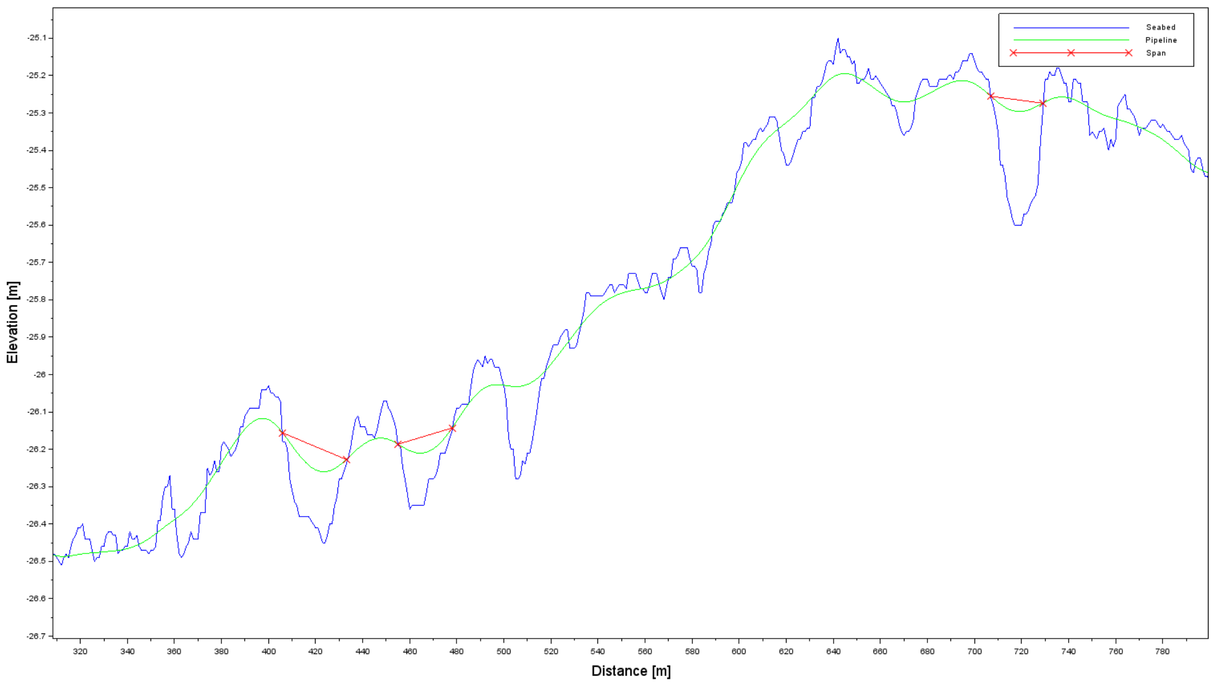


Figure 8-3 Pipeline on sea floor – section with spans >20m

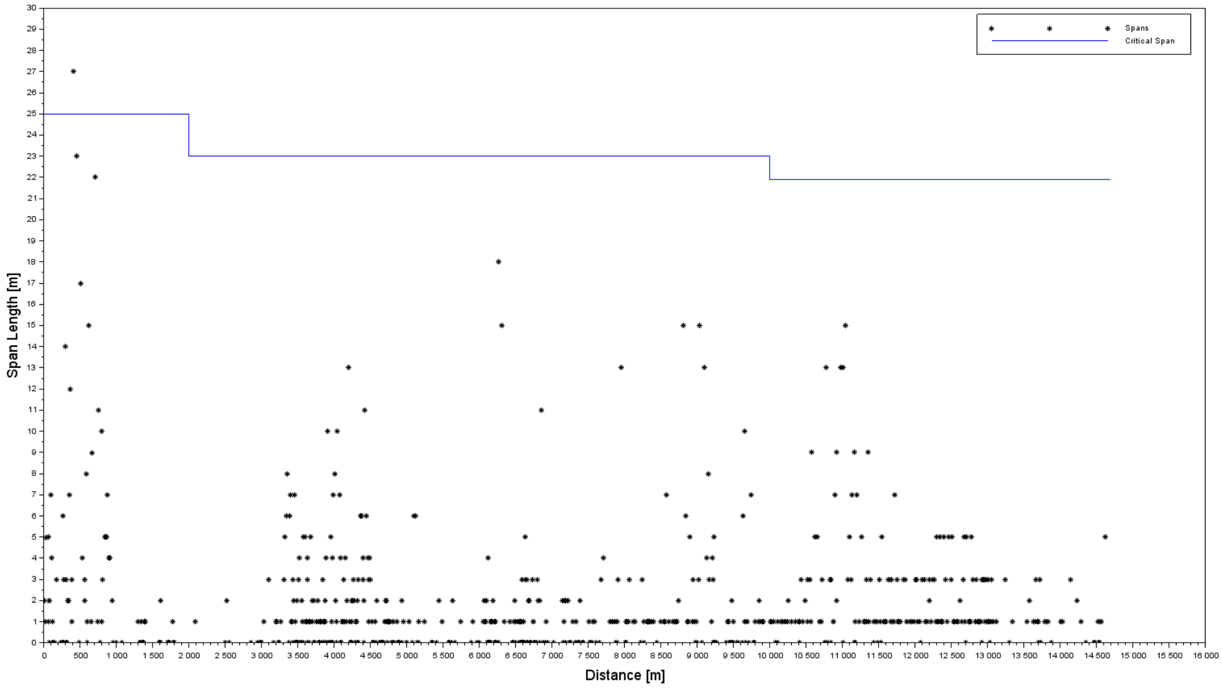


Figure 8-4 Overview of all spans and critical span

A. Wall Thickness Analysis

The following Wall Thickness Analyses were performed:

- 19018-60-CAL-01001-01-01 20” x 20.6 mm – inside 500m zone
- 19018-60-CAL-01001-01-01 20” x 20.6 mm – outside 500m zone

(4 pages)

Project	**:**	**N05-A Pipeline basic design**
Project #	**:**	19018
Subject	**:**	Wall thickness calculation N05-A Pipeline
File #	**:**	#N/A
Client	**:**	ONE-Dyas
Client File #	**:**	

Originator	: HvH		Checked	: PF
Date	: 21.10.2019			
Revision	: 01			

20" Pipeline - Inside 500m zone

Material properties

Material		=	L360NB	
Design temperature	T_d	=	50	°C
Yield at ambient temperature	R_e	=	360.00	N/mm^2
Yield at design temperature	R_{ed}	=	360.00	N/mm^2
Material factor (Table 4 NEN 3656)	γ_m	=	1.10	-
Allowable stress $\sigma_v = \frac{R_{ed}}{\gamma_m}$	σ_v	=	327.27	N/mm^2

Pipeline properties

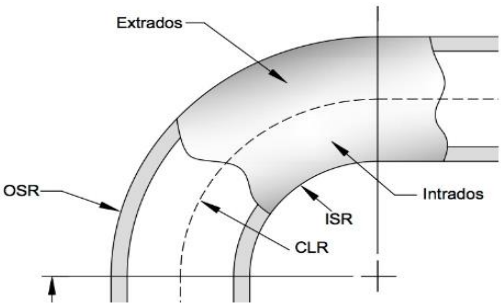
Outside diameter	OD	=	508	mm
Design pressure	P_d	=	111.1	barg
Minimum outside presssure	P_o	=	0	barg
Fabrication Tolerance	f_{tol}	=	7.3	%
Corrosion allowance	CA	=	3	mm
Pipeline within the 500 meter zone?			y	(Y or N)
Load factor (Table 3 NEN 3656): 1,25 outside 500m zone; 1,364 inside 500m zone	γ_s	=	1.364	-
Bend radius			2540	mm
Fabrication tolerance bends	f_{tolB}	=	7.3	%
Inside bend factor $\frac{2R-0.5D_e}{2R-D_e}$		=	1.06	
Outside bend factor $\frac{2R+0.5D_e}{2R+D_e}$		=	0.95	

Minimum wall thickness determination, d_{min}

minimum wall thickness (excl. CA): $d_{min} = \frac{\gamma_m \cdot \gamma_s \cdot P_d^* \cdot D_e}{2 \cdot R_e(T_d) + \gamma_m \cdot \gamma_s \cdot P_d^*}$ = 11.50 mm

Inside bend = 12.13 mm

Outside bend = 10.97 mm



Minimum required wall thickness (incl. CA) after bending, d_{min} [Note 2]

Straight part / along bend radius @ CLR	=	14.50	mm
Inside bend @ ISR	=	15.13	mm
Outside bend @ OSR	=	13.97	mm
Selected nominal wall thickness	=	20.6	mm

20" Pipeline - Inside 500m zone

Hoop stress

Hoop stress straight parts	$\sigma_{hoop} = \frac{\gamma_s \cdot P_d^* \cdot (D_e - d_{\min})}{2 \cdot d_{\min}}$	=	231.56	N/mm^2
Hoop stress inside bend	$\sigma_{hoop}(\mathrm{BI}) = \frac{2 \cdot R - \frac{1}{2} \cdot D_e}{2 \cdot \mathrm{R} - D_e} \cdot \sigma_{hoop}$	=	244.42	N/mm^2
Hoop stress outside bend	$\sigma_{hoop}(\mathrm{BO}) = \frac{2 \cdot R + \frac{1}{2} \cdot D_e}{2 \cdot \mathrm{R} + D_e} \cdot \sigma_{hoop}$	=	221.03	N/mm^2

Stress Check

Hoop stress (N/mm2)	Occurring	Allowable
Straight parts	231.56	327.27
Inside bend	244.42	327.27
Outside bend	221.03	327.27

Test pressure

Hydrotest temperature		=	15	°C
Yield at hydrotest temperature		=	360	N/mm^2
Product (gas / others)			gas	
Design factor, CP (1.3 for gas; 1.25 for others)			1.30	
Minimum hydrotest pressure	$P_{T,\min} = C_p \cdot P_d \cdot \frac{R_e(20^\circ C)}{R_e(T_d)}$	=	144.43	barg
Maximum allowable hydrotest pressure	$P_{T,\max} = \frac{2 \cdot d_{nom} \cdot (1 - f_{tol}) \cdot R_e(20^\circ C)}{(D_e - d_{nom} \cdot (1 - f_{tol}))}$	=	281.23	barg
Mill test pressure	$P_{T,mill} = 0.9 \cdot \frac{2 \cdot R_e \cdot d_{nom}}{D_e}$	=	262.77	barg

Max. allowable hydro test pressure exceeds mill test pressure!!

Note 1:	Outside 500m zone:	Pd***** = (Pd - Pe)
	Within 500m zone:	Pd***** = Pd
Note 2:	The bend manufacturer to ensure that the finished products does meet with these minimum WT. requirements.	

Project	**:**	**N05-A Pipeline basic design**
Project #	**:**	19018
Subject	**:**	Wall thickness calculation N05-A Pipeline
File #	**:**	19018-60-CAL-01001-02-01a_Wall thickness_20x20.6_L360_outside 500m.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	

Originator	: HvH		Checked	: PF
Date	: 21.10.2019			
Revision	: 01			

20" Pipeline - Outside 500m zone

Material properties

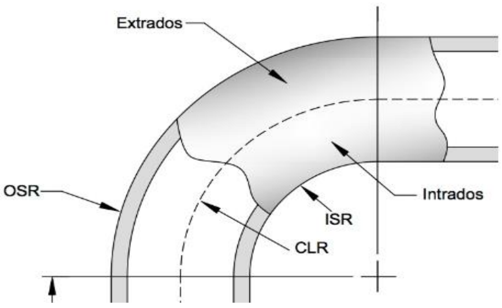
Material			=	L360NB	
Design temperature		T_d	=	50	°C
Yield at ambient temperature		R_e	=	360.00	N/mm^2
Yield at design temperature		R_{ed}	=	360.00	N/mm^2
Material factor (Table 4 NEN 3656)		γ_m	=	1.10	-
Allowable stress	$\sigma_v = \frac{R_{ed}}{\gamma_m}$	σ_v	=	327.27	N/mm^2

Pipeline properties

Outside diameter		OD	=	508	mm
Design pressure		P_d	=	111.1	barg
Minimum outside presssure		P_o	=	0	barg
Fabrication Tolerance		f_{tol}	=	7.3	%
Corrosion allowance		CA	=	3	mm
Pipeline within the 500 meter zone?				n	(Y or N)
Load factor (Table 3 NEN 3656): 1,25 outside 500m zone; 1,364 inside 500m zone		γ_s	=	1.250	-
Bend radius				2540	mm
Fabrication tolerance bends		f_{tolB}	=	7.3	%
Inside bend factor	$\frac{2R-0.5D_e}{2R-D_e}$		=	1.06	
Outside bend factor	$\frac{2R+0.5D_e}{2R+D_e}$		=	0.95	

Minimum wall thickness determination, d_{min}

minimum wall thickness (excl. CA):	$d_{\min} = \frac{\gamma_m \cdot \gamma_s \cdot P_d^* \cdot D_e}{2 \cdot R_e(T_d) + \gamma_m \cdot \gamma_s \cdot P_d^*}$	=	10.55	mm
Inside bend		=	11.14	mm
Outside bend		=	10.07	mm



Minimum required wall thickness (incl. CA) after bending, d_{min} [Note 2]

Straight part / along bend radius @ CLR	=	13.55	mm
Inside bend @ ISR	=	14.14	mm
Outside bend @ OSR	=	13.07	mm

Selected nominal wall thickness = 20.6 mm

Project	**:**	**N05-A Pipeline basic design**
Project #	**:**	19018
Subject	**:**	Wall thickness calculation N05-A Pipeline
File #	**:**	19018-60-CAL-01001-02-01a_Wall thickness_20x20.6_L360_outside 500m.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	

Originator : HvH   Checked : PF
Date : 21.10.2019
Revision : 01

20" Pipeline - Outside 500m zone

Hoop stress

Hoop stress straight parts $\sigma_{hoop} = \frac{\gamma_s \cdot P_d^* \cdot (D_e - d_{\min})}{2 \cdot d_{\min}}$ = 212.20 N/mm^2

Hoop stress inside bend $\sigma_{hoop}(\mathrm{BI}) = \frac{2 \cdot R - \frac{1}{2} \cdot D_e}{2 \cdot R - D_e} \cdot \sigma_{hoop}$ = 223.99 N/mm^2

Hoop stress outside bend $\sigma_{hoop}(\mathrm{BO}) = \frac{2 \cdot R + \frac{1}{2} \cdot D_e}{2 \cdot R + D_e} \cdot \sigma_{hoop}$ = 202.56 N/mm^2

Stress Check

Hoop stress (N/mm2)	Occurring	Allowable
Straight parts	212.20	327.27
Inside bend	223.99	327.27
Outside bend	202.56	327.27

Test pressure

Hydrotest temperature = 15 °C
Yield at hydrotest temperature = 360 N/mm^2

Product (gas / others) gas
Design factor, CP (1.3 for gas; 1.25 for others) 1.30

Minimum hydrotest pressure $P_{T,\min} = C_p \cdot P_d \cdot \frac{R_e(20^\circ C)}{R_e(T_d)}$ = 144.43 barg

Maximum allowable hydrotest pressure $P_{T,\max} = \frac{2 \cdot d_{nom} \cdot (1 - f_{tol}) \cdot R_e(20^\circ C)}{(D_e - d_{nom} \cdot (1 - f_{tol}))}$ = 281.23 barg

Mill test pressure $P_{T,mill} = 0.9 \cdot \frac{2 \cdot R_e \cdot d_{nom}}{D_e}$ = 262.77 barg

Max. allowable hydro test pressure exceeds mill test pressure!!

Note 1: Outside 500m zone: Pd***** = (Pd - Pe)
Within 500m zone: Pd***** = Pd

Note 2: The bend manufacturer to ensure that the finished products does meet with these minimum WT. requirements.

B. Buckling & Collapse Analysis

The following buckling and collapse analyses were performed:

- 19018-60-CAL-01003-01-01 Buckling & Collapse calculation – 26m – operation
- 19018-60-CAL-01003-02-01 Buckling & Collapse calculation – 26m – installation flooded
- 19018-60-CAL-01003-03-01 Buckling & Collapse calculation – 26m - hydrotest
- 19018-60-CAL-01003-04-01 Buckling & Collapse calculation – 8m - operation
- 19018-60-CAL-01003-05-01 Buckling & Collapse calculation – 8m - installation flooded
- 19018-60-CAL-01003-06-01 Buckling & Collapse calculation – 8m - hydrotest
- 19018-60-CAL-01003-07-01 Buckling & Collapse calculation – 17m - operation
- 19018-60-CAL-01003-08-01 Buckling & Collapse calculation – 17m - installation flooded
- 19018-60-CAL-01003-09-01 Buckling & Collapse calculation – 17m - hydrotest

(66 pages) only 26m with Stokes+hydroload pages

Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-01-01 - Buckling & Collapse calculations - 26m - operation.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	

enersea

Originator	: EvW	Checked	:
Date	: 24/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Operational

Situation

4
Operational

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom}	=	20	
Nominal diameter		OD_{nom}	=	508	mm
Nominal wall thickness		d_{nom}	=	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$	=	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$	=	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max}	=	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min}	=	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0	=	0.014	-
Cross sectional area of steel		A	=	31572	mm^2
Moment of Inertia		I	=	939135656	mm^4
Corrosion allowance		CA	=	3	mm
Fabrication Tolerance		f_{tol}	=	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min}	=	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g	=	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$	=	0	mm
Nominal wall thickness	$d_{nom,p}$	=	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-01-01 - Buckling & Collapse calculations - 26m - operation.xlsx
Client	: ONE-Dyas
Client File #	:

Originator	: EvW	Checked	:
Date	: 24/01/2020		
Revision	: 01		

Material

	=	L360NB	
Design temperature	T_d =	50	°C
Yield at ambient temperature	R_e =	360.00	N/mm^2
Yield at design temperature	R_{ed} =	360.00	N/mm^2
Density	ρ_{st} =	7850	kg/m^3
Youngs modulus	E_s =	210000	N/mm^2
Poisson's ratio	u =	0.3	-
Linear thermal expansion coefficient	a =	1.16E-05	$m/m/^oC$

Contents

Sea water density		1025	kg/m^3
Pipeline product density		96.1	kg/m^3
Pipeline content density used for this case:	Operational	96.1	kg/m^3

Pipeline Weights

$$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$$

$$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$$

Pipeline weight in air	$W_{pl,a}$ =	2636.6	N/m
Piggyback weight in air	$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback	$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty	$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight	$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty	$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled	$W_{T,s,f}$ =	2109.4	N/m

Soil

Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2

Environmental conditions

Water depths:

Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	29.68	m LAT
Minimum water depth		WD_{min} =	26	m LAT
Other water depth (to be used for calculations)		WD =	26	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-1.02	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.79	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	24.21	m LAT
Highest Astronomical Tide		HAT =	2.72	m

Waves (H_{max} & T_{max}):

Maximum wave height, RP1 yr - installation/hydrotes	$H_{max,1}$ =	11.4	m
Associated maximum wave period, RP1 yr	$T_{ass,1}$ =	10.1	s
Maximum wave height, RP100 yr - operational	$H_{max,100}$ =	16.9	m
Associated maximum wave period, RP100 yr	$T_{ass,100}$ =	11.5	s

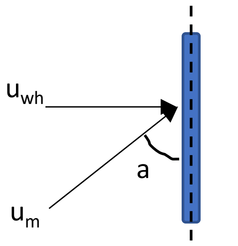
Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$\frac{H_{max}}{g \cdot T_z^2} =$ 0.0130

$\frac{SWL}{g \cdot T_z^2} =$ 0.0187

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th **2** Stokes 5th



Maximum wave particle velocity	u_{wm} =	4.00	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	4.00	m/s

Current:

Height above seabed at which velocity is known	z^* =	2	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.74	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.84	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	0.96	m/s
Current velocity at reference height	U_{czr} =	0.96	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\quad \frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.69	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 4320 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e) \cdot (p_c^2 - p_p^2) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $\quad P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3 =$ 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $\quad P_p = \frac{2 R_e d_{nom}}{OD_{nom}} =$ 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): $\quad P_c =$ 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $\quad WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT =$ 40.85 m

0.4085 N/mm^2

Actual external pressure (P_L) $\quad WC_{max} + SC_{pres} =$ 0.42 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ = **OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-
$n = 1 + 300 \cdot d_{nom} / OD_g$ n =	13.6	-

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 9.994E+05 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,**

q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W^{\ 2} \cdot W_S^{\ 2} + \gamma_H^{\ 2} \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws =	389	N/m
$F_D + F_I$ =	4320	N/m
g_w =	1.1	-
g_h =	1.2	-
Table 3 - NEN3656		
q =	5202	N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 9.99E+05 N·m

Maximum span length, L_{max} =	43.8	m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT = 46 -

R_e = 360.00 N/mm^2

R_{ed} = 360.00 N/mm^2

$$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$$

s_p = 169.3 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0005 < 0.0030 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment:

$$L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p = 1.15 -

g_t = 1.1 -

N = -2.05E+06 N

$L_{max,bb}$ = 61.7 m

Stokes 5th order wave theory

Water depth	WD =	26	m (LAT)
Storm surge	ss =	-1.79	m
Storm surge water level	$SWL = WD + ss$ =	24.21	m
Wave height	H =	16.9	m
Wave period	T =	11.5	s
Grav. Acceleration	g =	9.81	m/s^2
Deep water wave length	$L_o = \frac{g \cdot T^2}{2 \cdot \pi}$ =	206.5	m

Solving for wave length (L) and λ

$$\frac{\pi \cdot H}{SWL} - \frac{L}{SWL}\left\{\lambda + \lambda^3 \cdot B_{33} + \lambda^5 \cdot (B_{35} + B_{55})\right\} = 0 \quad (\text{ I })$$

$$\frac{SWL}{L_O} - \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right) \cdot \left\{1 + \lambda^2 \cdot C_1 + \lambda^4 \cdot C_2\right\} = 0 \quad (\text{ II })$$

Choosing L and solving for λ in (II) results in 4 roots for λ

Estimate actual wave length, L **184.228 m**

$A = SWL / L_O$ = 0.1172

$B = \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right)$ = 0.0891

$$\lambda = \pm\sqrt{X}$$

$$X = \frac{-C_1 \cdot B \pm \sqrt{D}}{2 \cdot C_2 \cdot B}$$

$D = (C_1 \cdot B)^2 - 4 \cdot (C_2 \cdot B) \cdot (-(A - B))$ = 0.5724

	-	eq. (I)	eq. (II)
λ1	0.227	-0.0004	0.0000
λ2	Numerator of X < 0		
λ3	-0.227	4.3864	0.0000
λ4	Numerator of X < 0		

Item	Formula	Value	Unit
s	$s = \sinh\left(\frac{2\cdot\pi\cdot WL}{L}\right) =$	0.9228	-
c	$c = \cosh\left(\frac{2\cdot\pi\cdot WL}{L}\right) =$	1.3607	-
A11	$A_{11} = \frac{1}{s} =$	1.0837	-
A13	$A_{13} = \frac{-c^2\cdot(5\cdot c^2+1)}{8\cdot s^5} =$	-3.5482	-
	$A_{15} = -\frac{1184\cdot c^{10} - 1440\cdot c^8 - 1992\cdot c^6 + 2641\cdot c^4 - 249\cdot c^2 + 18}{1536\cdot s^{11}} =$	-7.5755	-
A22	$A_{22} = \frac{3}{8\cdot s^4} =$	0.5172	-
A24	$A_{24} = \frac{192\cdot c^8 - 424\cdot c^6 - 312\cdot c^4 + 480\cdot c^2 - 17}{768\cdot s^{10}} =$	-1.8403	-
A33	$A_{33} = \frac{13 - 4\cdot c^2}{64\cdot s^7} =$	0.1534	-
	$A_{35} = \frac{512\cdot c^{12} + 4224\cdot c^{10} - 6800\cdot c^8 - 12808\cdot c^6 + 16704\cdot c^4 - 3154\cdot c^2 - 107}{4096\cdot s^{13}\cdot(6\cdot c^2 - 1)} =$	0.1815	-
A44	$A_{44} = \frac{80\cdot c^6 - 816\cdot c^4 + 1338\cdot c^2 - 197}{1536\cdot s^{10}\cdot(6\cdot c^2 - 1)} =$	-0.0013	-

$$A_{55} = -\frac{2880 \cdot c^{10} - 72480 \cdot c^{8} + 324000 \cdot c^{6} - 432000 \cdot c^{4} + 163470 \cdot c^{2} - 16245}{61440 \cdot s^{11} \cdot (6 \cdot c^{2} - 1) \cdot (8 \cdot c^{4} - 11 \cdot c^{2} + 3)} =$$ -0.0282 -

B22 $$B_{22} = \frac{(2 \cdot c^{2} + 1) \cdot c}{4 \cdot s^{3}} =$$ 2.0361 -

B24 $$B_{24} = \frac{c \cdot (272 \cdot c^{8} - 504 \cdot c^{6} - 192 \cdot c^{4} + 322 \cdot c^{2} + 21)}{384 \cdot s^{9}} =$$ -0.3177 -

B33 $$B_{33} = \frac{3 \cdot (8 \cdot c^{6} + 1)}{64 \cdot s^{6}} =$$ 3.9311 -

$$B_{35} = \frac{88128 \cdot c^{14} - 208224 \cdot c^{12} + 70848 \cdot c^{10} + 54000 \cdot c^{8} - 21816 \cdot c^{6} + 6264 \cdot c^{4} - 54 \cdot c^{2} - 81}{12288 \cdot s^{12} \cdot (6 \cdot c^{2} - 1)} =$$
= 5.1509 -

B44 $$B_{44} = c \cdot \frac{768 \cdot c^{10} - 488 \cdot c^{8} - 48 \cdot c^{6} + 48 \cdot c^{4} + 106 \cdot c^{2} - 21}{384 \cdot s^{9} \cdot (6 \cdot c^{2} - 1)} =$$ 7.9561 -

$$B_{55} = \frac{192000 \cdot c^{16} - 26720 \cdot c^{14} + 83680 \cdot c^{12} + 20160 \cdot c^{10} - 7280 \cdot c^{8} + 7160 \cdot c^{6} - 1800 \cdot c^{4} - 1050 \cdot c^{2} + 225}{12288 \cdot s^{10} \cdot (8 \cdot c^{4} - 11 \cdot c^{2} + 3) \cdot (6 \cdot c^{2} - 1)} =$$
= 19.0981 -

C1 $$C_{1} = \frac{8 \cdot c^{4} - 8 \cdot c^{2} + 9}{8 \cdot s^{4}} =$$ 3.7260 -

$$C_{2} = \frac{3840 \cdot c^{12} - 4096 \cdot c^{10} + 2592 \cdot c^{8} - 1008 \cdot c^{6} + 5944 \cdot c^{4} - 1830 \cdot c^{2} + 147}{512 \cdot s^{10} \cdot (6 \cdot c^{2} - 1)} =$$ 46.0838 -

C3 $$C_{3} = -\frac{1}{4 \cdot c \cdot s} =$$ -0.1991 -

C4 $$C_{4} = \frac{12 \cdot c^{8} + 36 \cdot c^{6} - 162 \cdot c^{4} + 141 \cdot c^{2} - 27}{192 \cdot c \cdot s^{9}} =$$ 0.3806 -

K1 $$K_{1} = \lambda \cdot A_{11} + \lambda^{3} \cdot A_{13} + \lambda^{5} \cdot A_{15} =$$ 0.2001 -

K2	$K_2 = \lambda^2 \cdot A_{22} + \lambda^4 \cdot A_{24} =$	0.0218	-
K3	$K_3 = \lambda^3 \cdot A_{33} + \lambda^5 \cdot A_{35} =$	0.0019	-
K4	$K_4 = \lambda^4 \cdot A_{44} =$	0.0000	-
K5	$K_5 = \lambda^5 \cdot A_{55} =$	0.0000	-

Project	:	**N05-A Pipeline design**
Project #	:	19018
Subject	:	Buckling and Collapse
File #	:	19018-60-CAL-01003-01-01 - Buckling & Collapse calculations - 26m - operation.xlsx
Client	:	ONE-Dyas
Client File #	:	

Originator	: EvW	Checked	:
Date	: 24/01/2020		
Revision	: 01		

Horizontal wave particle velocities

Water depth at which data required, z (w.r.t. seabed): 0.5080 m

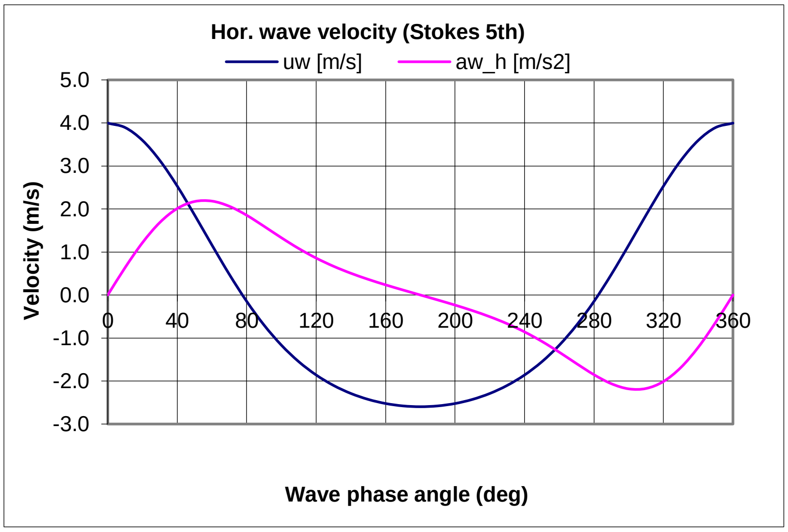
Horizontal velocity, u_w

$$u_w = \frac{L}{T} \cdot \sum_{n=1}^{5} n \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \cos(n \cdot \varphi)$$

Horizontal acceleration, $a_{w,h}$

$$a_{w,h} = \frac{2 \cdot \pi \cdot L}{T^2} \cdot \sum_{n=1}^{5} n^2 \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \sin(n \cdot \varphi)$$

ϕ [deg.]	uw [m/s]	aw_h [m/s^2]
0.00	3.9954	0.0000
10.00	3.8927	0.6377
20.00	3.5942	1.2167
30.00	3.1271	1.6861
40.00	2.5326	2.0102
50.00	1.8601	2.1734
60.00	1.1605	2.1823
70.00	0.4796	2.0627
80.00	-0.1478	1.8534
90.00	-0.6996	1.5968
100.00	-1.1669	1.3301
110.00	-1.5511	1.0793
120.00	-1.8596	0.8578
130.00	-2.1025	0.6679
140.00	-2.2893	0.5054
150.00	-2.4276	0.3633
160.00	-2.5229	0.2353
170.00	-2.5788	0.1156
180.00	-2.5972	0.0000
190.00	-2.5788	-0.1156
200.00	-2.5229	-0.2353



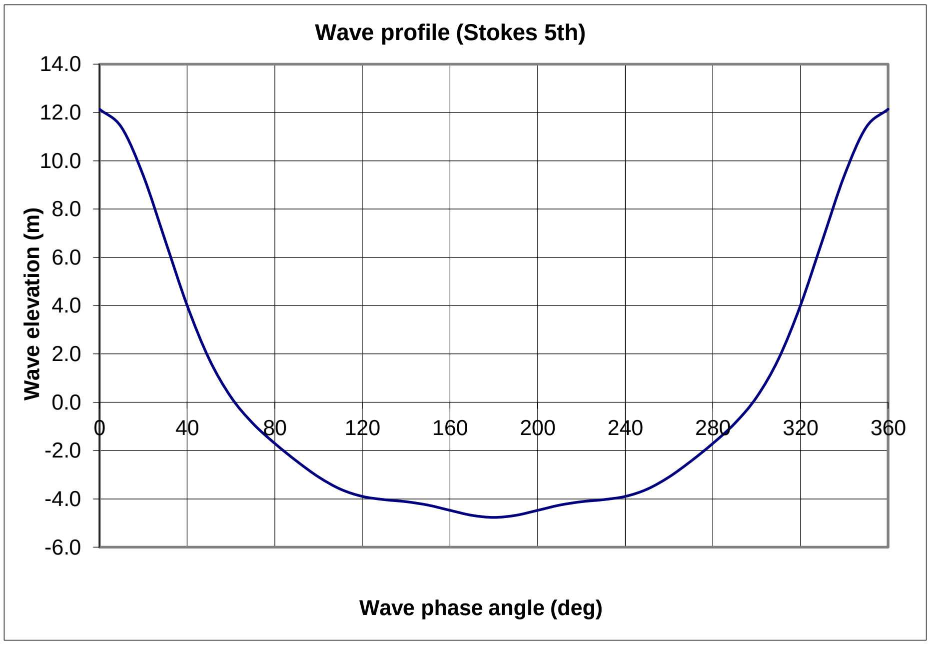
210.00	-2.4276	-0.3633
220.00	-2.2893	-0.5054
230.00	-2.1025	-0.6679
240.00	-1.8596	-0.8578
250.00	-1.5511	-1.0793
260.00	-1.1669	-1.3301
270.00	-0.6996	-1.5968
280.00	-0.1478	-1.8534
290.00	0.4796	-2.0627
300.00	1.1605	-2.1823
310.00	1.8601	-2.1734
320.00	2.5326	-2.0102
330.00	3.1271	-1.6861
340.00	3.5942	-1.2167
350.00	3.8927	-0.6377
360.00	3.9954	0.0000

U_{wm} = max. wave particle velocity = 4.00 m/s

Wave profile h(t)

$$\eta(t)=\frac{L}{2\cdot\pi}\left\{\lambda\cdot\cos(\varphi)+\left(\lambda^2\cdot B_{22}+\lambda^4\cdot B_{24}\right)\cdot\cos(2\varphi)+\left(\lambda^3\cdot B_{33}+\lambda^5\cdot B_{35}\right)\cdot\cos(3\varphi)+\lambda^4\cdot B_{44}\cdot\cos(4\varphi)+\lambda^5\cdot B_{55}\cdot\cos(5\varphi)\right\}$$

ϕ (deg.)	η(t) (m)
0.00	12.1350
10.00	11.3883
20.00	9.3802
30.00	6.6968
40.00	4.0097
50.00	1.7992
60.00	0.2151
70.00	-0.8738
80.00	-1.7036
90.00	-2.4374
100.00	-3.0936
110.00	-3.5987
120.00	-3.8987
130.00	-4.0330
140.00	-4.1177
150.00	-4.2594
160.00	-4.4749
170.00	-4.6819
180.00	-4.7680
190.00	-4.6819
200.00	-4.4749
210.00	-4.2594
220.00	-4.1177
230.00	-4.0330
240.00	-3.8987
250.00	-3.5987
260.00	-3.0936
270.00	-2.4374
280.00	-1.7036
290.00	-0.8738
300.00	0.2151
310.00	1.7992
320.00	4.0097
330.00	6.6968
340.00	9.3802
350.00	11.3883
360.00	12.1350



Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-02-01 - Buckling & Collapse calculations - 26m - installation flooded.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01003-02-01 - Buckling & Collapse calculations - 26m - installation flooded.xlsx

Originator	: EvW	Checked :
Date	: 24/01/2020	
Revision	: 01	

Buckling and Collapse - 20in x 20.62mm - Installation: filled

Situation

2
Installation: filled

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

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Originator	: EvW	Checked	:
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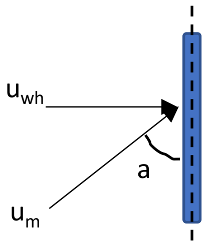
Material		=	L360NB	
Design temperature		T_d =	15	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	$m/m/^oC$
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Installation: filled		1025	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	4195.8	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	29.68	m LAT
Minimum water depth		WD_{min} =	26	m LAT
Other water depth (to be used for calculations)		WD =	26	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-1.02	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.79	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	24.98	m LAT
Highest Astronomical Tide		HAT =	2.72	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	11.4	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	10.1	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	16.9	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	11.5	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures") $\frac{H_{max}}{g\cdot T_z^2} =$ 0.0114

$\frac{SWL}{g\cdot T_z^2} =$ 0.0250

Wave theory selected:
1. Airy/linear wave; 2. Stokes 5th **2** Stokes 5th



Maximum wave particle velocity	u_{wm} =	2.39	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	2.39	m/s

Current:

Height above seabed at which velocity is known	z* =	2	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.74	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.84	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	0.96	m/s
Current velocity at reference height	U_{czr} =	0.74	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8}\cdot U_{czr}\cdot\left(\frac{OD_{nom}}{z_r}\right)^{1/7}\cdot\sin(\alpha_{uc}) =$	u_{ch} =	0.53	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 1822 N/m

Temperatures:
Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e)\cdot\left(p_c^2 - p_p^2\right) = p_c\cdot p_e\cdot p_p\cdot 2\cdot\delta_o\cdot\frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm²

External plastic pipe collapse pressure (P_p) $P_p = \frac{2\,R_e\,d_{nom}}{OD_{nom}}$ = 29.2 N/mm²

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm²

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5\cdot H_{max,100} + HAT$ = 40.85 m
0.4085 N/mm²

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.42 N/mm²

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **= OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-
$n = 1 + 300 \cdot d_{nom} / OD_g$ n =	13.6	-

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 9.994E+05 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,** q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws =	2109	N/m
$F_D + F_I$ =	1822	N/m
g_w =	1.1	-
g_h =	1.2	-
Table 3 - NEN3656		
q =	3188	N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 9.99E+05 N·m

Maximum span length, L_{max} = 56.0 m

Originator	: EvW	Checked	:
Date	: 24/01/2020		
Revision	: 01		

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E}\sqrt{1-\frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9-\frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2}\right]$

Temperature difference with ambient; DT	=	11	-
R_e	=	360.00	N/mm^2
R_{ed}	=	360.00	N/mm^2

$$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$$

s_p = 3.1 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E}\sqrt{1-\frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9-\frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2}\right]$$

Assessment: 0.0001 < 0.0033 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p	=	1.15	-
g_t	=	1.1	-
N	=	-8.97E+05	N
$L_{max,bb}$	**=**	**93.1**	**m**

Stokes 5th order wave theory

Water depth	WD =	26	m (LAT)
Storm surge	ss =	-1.02	m
Storm surge water level	$SWL = WD + ss$ =	24.98	m
Wave height	H =	11.4	m
Wave period	T =	10.1	s
Grav. Acceleration	g =	9.81	m/s^2
Deep water wave length	$L_o = \dfrac{g \cdot T^2}{2 \cdot \pi}$ =	159.3	m

Solving for wave length (L) and λ

$$\frac{\pi \cdot H}{SWL} - \frac{L}{SWL}\left\{\lambda + \lambda^3 \cdot B_{33} + \lambda^5 \cdot (B_{35} + B_{55})\right\} = 0 \quad (\text{I})$$

$$\frac{SWL}{L_O} - \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right) \cdot \left\{1 + \lambda^2 \cdot C_1 + \lambda^4 \cdot C_2\right\} = 0 \quad (\text{II})$$

Choosing L and solving for λ in (II) results in 4 roots for λ

Estimate actual wave length, L = **143.093 m**

$$A = SWL/L_O = 0.1568$$

$$B = \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right) = 0.1395$$

$$\lambda = \pm\sqrt{X}$$

$$X = \frac{-C_1 \cdot B \pm \sqrt{D}}{2 \cdot C_2 \cdot B}$$

$$D = (C_1 \cdot B)^2 - 4 \cdot (C_2 \cdot B) \cdot (-(A - B)) = 0.1581$$

	-	eq. (I)	eq. (II)
λ1	0.228	0.0005	0.0000
λ2	Numerator of X < 0		
λ3	-0.228	2.8669	0.0000
λ4	Numerator of X < 0		

Item	Formula	Value	Unit
s	$s = \sinh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.3304	-
c	$c = \cosh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.6643	-
A11	$A_{11} = \frac{1}{s} =$	0.7516	-
A13	$A_{13} = \frac{-c^2 \cdot (5 \cdot c^2 + 1)}{8 \cdot s^5} =$	-1.2336	-
	$A_{15} = -\frac{1184 \cdot c^{10} - 1440 \cdot c^8 - 1992 \cdot c^6 + 2641 \cdot c^4 - 249 \cdot c^2 + 18}{1536 \cdot s^{11}} =$	-2.4101	-
A22	$A_{22} = \frac{3}{8 \cdot s^4} =$	0.1197	-
A24	$A_{24} = \frac{192 \cdot c^8 - 424 \cdot c^6 - 312 \cdot c^4 + 480 \cdot c^2 - 17}{768 \cdot s^{10}} =$	0.0907	-
A33	$A_{33} = \frac{13 - 4 \cdot c^2}{64 \cdot s^7} =$	0.0041	-
	$A_{35} = \frac{512 \cdot c^{12} + 4224 \cdot c^{10} - 6800 \cdot c^8 - 12808 \cdot c^6 + 16704 \cdot c^4 - 3154 \cdot c^2 - 107}{4096 \cdot s^{13} \cdot (6 \cdot c^2 - 1)} =$	0.1402	-
A44	$A_{44} = \frac{80 \cdot c^6 - 816 \cdot c^4 + 1338 \cdot c^2 - 197}{1536 \cdot s^{10} \cdot (6 \cdot c^2 - 1)} =$	-0.0025	-

$$A_{55} = -\frac{2880\cdot c^{10} - 72480\cdot c^{8} + 324000\cdot c^{6} - 432000\cdot c^{4} + 163470\cdot c^{2} - 16245}{61440\cdot s^{11}\cdot(6\cdot c^{2}-1)\cdot(8\cdot c^{4} - 11\cdot c^{2} + 3)} =$$ -0.0003 -

B22 $$B_{22} = \frac{(2\cdot c^{2}+1)\cdot c}{4\cdot s^{3}} =$$ 1.1556 -

B24 $$B_{24} = \frac{c\cdot(272\cdot c^{8} - 504\cdot c^{6} - 192\cdot c^{4} + 322\cdot c^{2} + 21)}{384\cdot s^{9}} =$$ 1.5737 -

B33 $$B_{33} = \frac{3\cdot(8\cdot c^{6}+1)}{64\cdot s^{6}} =$$ 1.4457 -

$$B_{35} = \frac{88128\cdot c^{14} - 208224\cdot c^{12} + 70848\cdot c^{10} + 54000\cdot c^{8} - 21816\cdot c^{6} + 6264\cdot c^{4} - 54\cdot c^{2} - 81}{12288\cdot s^{12}\cdot(6\cdot c^{2}-1)} =$$
= 5.1727 -

B44 $$B_{44} = c\cdot\frac{768\cdot c^{10} - 488\cdot c^{8} - 48\cdot c^{6} + 48\cdot c^{4} + 106\cdot c^{2} - 21}{384\cdot s^{9}\cdot(6\cdot c^{2}-1)} =$$ 2.0428 -

$$B_{55} = \frac{192000\cdot c^{16} - 26720\cdot c^{14} + 83680\cdot c^{12} + 20160\cdot c^{10} - 7280\cdot c^{8} + 7160\cdot c^{6} - 1800\cdot c^{4} - 1050\cdot c^{2} + 225}{12288\cdot s^{10}\cdot(8\cdot c^{4} - 11\cdot c^{2} + 3)\cdot(6\cdot c^{2}-1)} =$$
= 3.3386 -

C1 $$C_{1} = \frac{8\cdot c^{4} - 8\cdot c^{2} + 9}{8\cdot s^{4}} =$$ 1.9240 -

$$C_{2} = \frac{3840\cdot c^{12} - 4096\cdot c^{10} + 2592\cdot c^{8} - 1008\cdot c^{6} + 5944\cdot c^{4} - 1830\cdot c^{2} + 147}{512\cdot s^{10}\cdot(6\cdot c^{2}-1)} =$$ 8.9142 -

C3 $$C_{3} = -\frac{1}{4\cdot c\cdot s} =$$ -0.1129 -

C4 $$C_{4} = \frac{12\cdot c^{8} + 36\cdot c^{6} - 162\cdot c^{4} + 141\cdot c^{2} - 27}{192\cdot c\cdot s^{9}} =$$ 0.1419 -

K1 $$K_{1} = \lambda\cdot A_{11} + \lambda^{3}\cdot A_{13} + \lambda^{5}\cdot A_{15} =$$ 0.1552 -

K2	$K_2 = \lambda^2 \cdot A_{22} + \lambda^4 \cdot A_{24} =$	0.0065	-
K3	$K_3 = \lambda^3 \cdot A_{33} + \lambda^5 \cdot A_{35} =$	0.0001	-
K4	$K_4 = \lambda^4 \cdot A_{44} =$	0.0000	-
K5	$K_5 = \lambda^5 \cdot A_{55} =$	0.0000	-

Horizontal wave particle velocities

Water depth at which data required, z (w.r.t. seabed) 0.5080 m

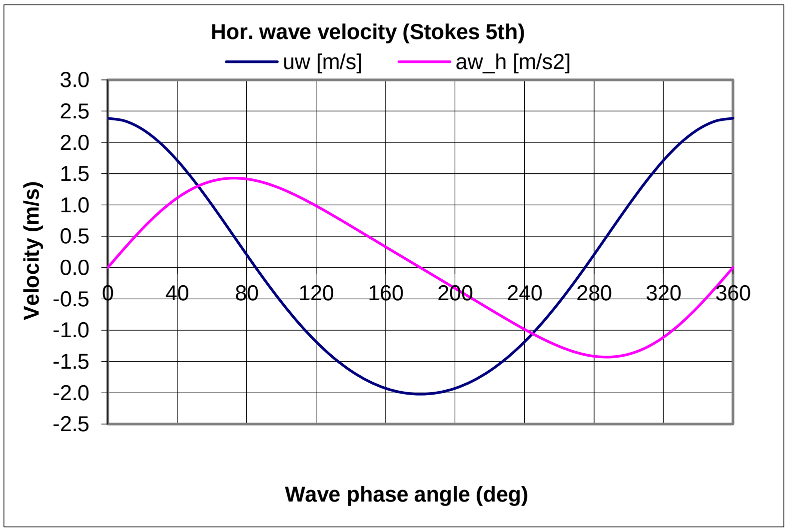
Horizontal velocity, u_w

$$u_w = \frac{L}{T} \cdot \sum_{n=1}^{5} n \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \cos(n \cdot \varphi)$$

Horizontal acceleration, $a_{w,h}$

$$a_{w,h} = \frac{2 \cdot \pi \cdot L}{T^2} \cdot \sum_{n=1}^{5} n^2 \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \sin(n \cdot \varphi)$$

ϕ [deg.]	uw [m/s]	aw_h [m/s^2]
0.00	2.3878	0.0000
10.00	2.3427	0.3202
20.00	2.2098	0.6227
30.00	1.9965	0.8913
40.00	1.7141	1.1129
50.00	1.3773	1.2783
60.00	1.0025	1.3832
70.00	0.6068	1.4278
80.00	0.2066	1.4167
90.00	-0.1836	1.3575
100.00	-0.5515	1.2596
110.00	-0.8877	1.1329
120.00	-1.1853	0.9867
130.00	-1.4402	0.8286
140.00	-1.6498	0.6646
150.00	-1.8129	0.4982
160.00	-1.9293	0.3316
170.00	-1.9990	0.1655
180.00	-2.0222	0.0000
190.00	-1.9990	-0.1655
200.00	-1.9293	-0.3316



210.00	-1.8129	-0.4982
220.00	-1.6498	-0.6646
230.00	-1.4402	-0.8286
240.00	-1.1853	-0.9867
250.00	-0.8877	-1.1329
260.00	-0.5515	-1.2596
270.00	-0.1836	-1.3575
280.00	0.2066	-1.4167
290.00	0.6068	-1.4278
300.00	1.0025	-1.3832
310.00	1.3773	-1.2783
320.00	1.7141	-1.1129
330.00	1.9965	-0.8913
340.00	2.2098	-0.6227
350.00	2.3427	-0.3202
360.00	2.3878	0.0000

U_{wm} = max. wave particle velocity = 2.39 m/s

Wave profile h(t)

$$\eta(t)=\frac{L}{2\cdot\pi}\left\{\lambda\cdot\cos(\varphi)+\left(\lambda^2\cdot B_{22}+\lambda^4\cdot B_{24}\right)\cdot\cos(2\varphi)+\left(\lambda^3\cdot B_{33}+\lambda^5\cdot B_{35}\right)\cdot\cos(3\varphi)+\lambda^4\cdot B_{44}\cdot\cos(4\varphi)+\lambda^5\cdot B_{55}\cdot\cos(5\varphi)\right\}$$

ϕ (deg.)	η(t) (m)
0.00	7.2865
10.00	7.0115
20.00	6.2418
30.00	5.1225
40.00	3.8366
50.00	2.5478
60.00	1.3619
70.00	0.3219
80.00	-0.5728
90.00	-1.3376
100.00	-1.9847
110.00	-2.5198
120.00	-2.9504
130.00	-3.2916
140.00	-3.5642
150.00	-3.7849
160.00	-3.9567
170.00	-4.0697
180.00	-4.1095
190.00	-4.0697
200.00	-3.9567
210.00	-3.7849
220.00	-3.5642
230.00	-3.2916
240.00	-2.9504
250.00	-2.5198
260.00	-1.9847
270.00	-1.3376
280.00	-0.5728
290.00	0.3219
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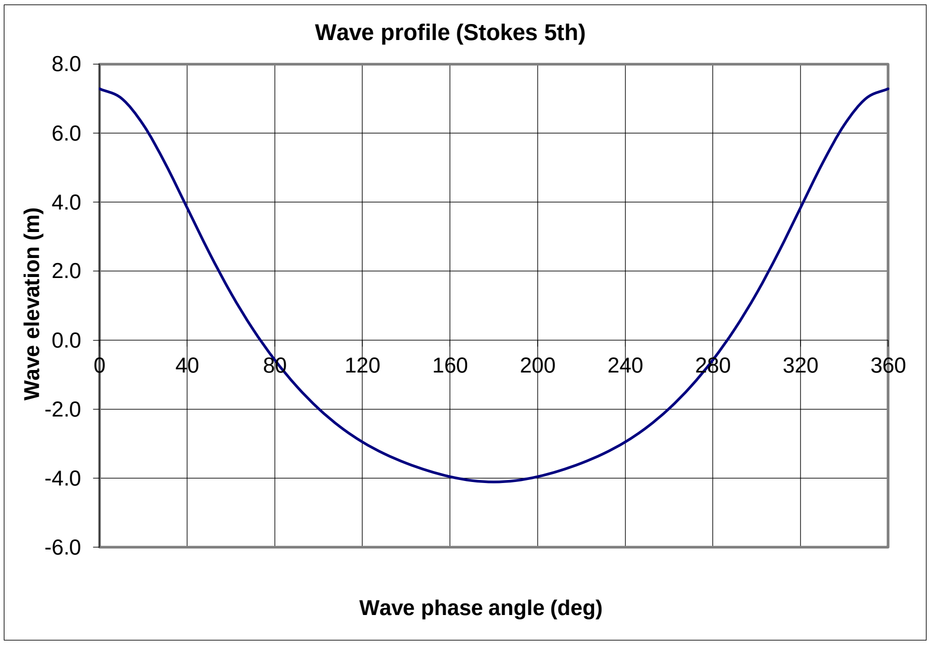

Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-03-01 - Buckling & Collapse calculations - 26m - hydrotest.xlsx
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01003-03-01 - Buckling & Collapse calculations - 26m - hydrotest.xlsx

Originator	: EvW	Checked	:
Date	: 24/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Hydrotest

Situation

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

3
Hydrotest

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	: **N05-A Pipeline design**	
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Material

		=	L360NB	
Design temperature	T_d	=	15	°C
Yield at ambient temperature	R_e	=	360.00	N/mm^2
Yield at design temperature	R_{ed}	=	360.00	N/mm^2
Density	ρ_{st}	=	7850	kg/m^3
Youngs modulus	E_s	=	210000	N/mm^2
Poisson's ratio	u	=	0.3	-
Linear thermal expansion coefficient	a	=	1.16E-05	$m/m/^oC$

Contents

Sea water density		1025	kg/m^3
Pipeline product density		96.1	kg/m^3
Pipeline content density used for this case:	Hydrotest	1025	kg/m^3

Pipeline Weights

$$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$$

Pipeline weight in air	$W_{pl,a}$	=	4195.8	N/m
Piggyback weight in air	$W_{pg,a}$	=	0.0	N/m

$$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$$

Buoyancy force pipeline	$F_{B,pl}$	=	2086.5	N/m
Buoyancy force piggyback	$F_{B,pb}$	=	0.0	N/m
Submerged pipeline weight,empty	$W_{pl,s,e}$	=	388.8	N/m
Submerged piggyback weight	$W_{pg,s}$	=	0.0	N/m
Total submerged bundle weight,empty	$W_{T,s,e}$	=	388.8	N/m
Total submerged bundle weight,water filled	$W_{T,s,f}$	=	2109.4	N/m

Soil

Submerged density		ρ_{ss}	=	1000	kg/m^3
Depth of burial		d_b	=	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres}	=	0.008	N/mm^2

Environmental conditions

Water depths:

Seawater density		ρ_{sw}	=	1025	kg/m3
Maximum water depth		WD_{max}	=	29.68	m LAT
Minimum water depth		WD_{min}	=	26	m LAT
Other water depth (to be used for calculations)		WD	=	26	m LAT
Storm surge, RP1 yr		ss_{1yr}	=	-1.02	m LAT
Storm surge, RP100 yr		ss_{100yr}	=	-1.79	m LAT
Storm surge water level	SSWL = WD + ss	SSWL	=	24.98	m LAT
Highest Astronomical Tide		HAT	=	2.72	m

Waves (H_{max} & T_{max}):

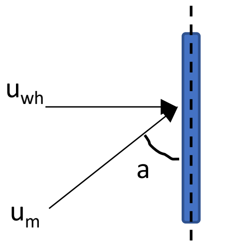
Maximum wave height, RP1 yr - installation/hydrotes	$H_{max,1}$	=	11.4	m
Associated maximum wave period, RP1 yr	$T_{ass,1}$	=	10.1	s
Maximum wave height, RP100 yr - operational	$H_{max,100}$	=	16.9	m
Associated maximum wave period, RP100 yr	$T_{ass,100}$	=	11.5	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$$\frac{H_{max}}{g \cdot T_z^2} = 0.0114$$

$$\frac{SWL}{g \cdot T_z^2} = 0.0250$$

Wave theory selected:
1. Airy/linear wave; 2. Stokes 5th — **2** — Stokes 5th



Maximum wave particle velocity	u_{wm} =	2.39	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	2.39	m/s

Current:

Height above seabed at which velocity is known	z* =	2	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.74	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.84	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	0.96	m/s
Current velocity at reference height	U_{czr} =	0.74	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.53	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 1822 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e)\cdot\left(p_c^2 - p_p^2\right) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}}$ = 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT$ = 40.85 m
0.4085 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.42 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -
g_M = 0.93 -
$g_{m,p}$ = 1.45 -

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ = **OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ = 1.1 -
g_M = 1 -
$g_{m,M}$ = 1.3 -

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c/\gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c/\gamma_{m,M}}\right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -
$g_{g,M}$ = 1.55 -
$g_{m,p}$ = 1.25 -
$g_{m,M}$ = 1.15 -
g_M = 0.93 -
$n = 1 + 300 \cdot d_{nom} / OD_g$ n = 13.6 -

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 9.994E+05 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,** q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws = 2109 N/m
$F_D + F_I$ = 1822 N/m
g_w = 1.1 -
g_h = 1.2 -
Table 3 - NEN3656
q = 3188 N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 9.99E+05 N·m

Maximum span length, L_{max} = 56.0 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT = 11 -

R_e = 360.00 N/mm^2

R_{ed} = 360.00 N/mm^2

$$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$$

s_p = 219.6 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0001 < 0.0028 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p = 1.15 -

g_t = 1.1 -

N = 1.46E+06 N

$L_{max,bb}$ = No compressive force m

Stokes 5th order wave theory

Water depth	WD =	26	m (LAT)
Storm surge	ss =	-1.02	m
Storm surge water level	$SWL = WD + ss$ =	24.98	m
Wave height	H =	11.4	m
Wave period	T =	10.1	s
Grav. Acceleration	g =	9.81	m/s^2
Deep water wave length	$L_o = \dfrac{g \cdot T^2}{2 \cdot \pi}$ =	159.3	m

Solving for wave length (L) and λ

$$\frac{\pi \cdot H}{SWL} - \frac{L}{SWL}\left\{\lambda + \lambda^3 \cdot B_{33} + \lambda^5 \cdot (B_{35} + B_{55})\right\} = 0 \quad (\mathrm{I})$$

$$\frac{SWL}{L_O} - \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right) \cdot \left\{1 + \lambda^2 \cdot C_1 + \lambda^4 \cdot C_2\right\} = 0 \quad (\mathrm{II})$$

Choosing L and solving for λ in (II) results in 4 roots for λ

Estimate actual wave length, L **143.093** **m**

$A = SWL / L_O$ = 0.1568

$B = \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right)$ = 0.1395

$$\lambda = \pm \sqrt{X}$$

$$X = \frac{-C_1 \cdot B \pm \sqrt{D}}{2 \cdot C_2 \cdot B}$$

$D = (C_1 \cdot B)^2 - 4 \cdot (C_2 \cdot B) \cdot (-(A - B))$ = 0.1581

	-	eq. (I)	eq. (II)
λ1	0.228	0.0005	0.0000
λ2	Numerator of X < 0		
λ3	-0.228	2.8669	0.0000
λ4	Numerator of X < 0		

Item	**Formula**	**Value**	**Unit**
s	$s = \sinh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.3304	-
c	$c = \cosh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.6643	-
A11	$A_{11} = \frac{1}{s} =$	0.7516	-
A13	$A_{13} = \frac{-c^2 \cdot (5 \cdot c^2 + 1)}{8 \cdot s^5} =$	-1.2336	-
	$A_{15} = -\frac{1184 \cdot c^{10} - 1440 \cdot c^8 - 1992 \cdot c^6 + 2641 \cdot c^4 - 249 \cdot c^2 + 18}{1536 \cdot s^{11}} =$	-2.4101	-
A22	$A_{22} = \frac{3}{8 \cdot s^4} =$	0.1197	-
A24	$A_{24} = \frac{192 \cdot c^8 - 424 \cdot c^6 - 312 \cdot c^4 + 480 \cdot c^2 - 17}{768 \cdot s^{10}} =$	0.0907	-
A33	$A_{33} = \frac{13 - 4 \cdot c^2}{64 \cdot s^7} =$	0.0041	-
	$A_{35} = \frac{512 \cdot c^{12} + 4224 \cdot c^{10} - 6800 \cdot c^8 - 12808 \cdot c^6 + 16704 \cdot c^4 - 3154 \cdot c^2 - 107}{4096 \cdot s^{13} \cdot (6 \cdot c^2 - 1)} =$	0.1402	-
A44	$A_{44} = \frac{80 \cdot c^6 - 816 \cdot c^4 + 1338 \cdot c^2 - 197}{1536 \cdot s^{10} \cdot (6 \cdot c^2 - 1)} =$	-0.0025	-

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Originator	: EvW	Checked	:
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$$A_{55} = -\frac{2880 \cdot c^{10} - 72480 \cdot c^8 + 324000 \cdot c^6 - 432000 \cdot c^4 + 163470 \cdot c^2 - 16245}{61440 \cdot s^{11} \cdot (6 \cdot c^2 - 1) \cdot (8 \cdot c^4 - 11 \cdot c^2 + 3)} =$$ -0.0003 -

B22 $$B_{22} = \frac{(2 \cdot c^2 + 1) \cdot c}{4 \cdot s^3} =$$ 1.1556 -

B24 $$B_{24} = \frac{c \cdot (272 \cdot c^8 - 504 \cdot c^6 - 192 \cdot c^4 + 322 \cdot c^2 + 21)}{384 \cdot s^9} =$$ 1.5737 -

B33 $$B_{33} = \frac{3 \cdot (8 \cdot c^6 + 1)}{64 \cdot s^6} =$$ 1.4457 -

$$B_{35} = \frac{88128 \cdot c^{14} - 208224 \cdot c^{12} + 70848 \cdot c^{10} + 54000 \cdot c^8 - 21816 \cdot c^6 + 6264 \cdot c^4 - 54 \cdot c^2 - 81}{12288 \cdot s^{12} \cdot (6 \cdot c^2 - 1)} =$$
= 5.1727 -

B44 $$B_{44} = c \cdot \frac{768 \cdot c^{10} - 488 \cdot c^8 - 48 \cdot c^6 + 48 \cdot c^4 + 106 \cdot c^2 - 21}{384 \cdot s^9 \cdot (6 \cdot c^2 - 1)} =$$ 2.0428 -

$$B_{55} = \frac{192000 \cdot c^{16} - 26720 \cdot c^{14} + 83680 \cdot c^{12} + 20160 \cdot c^{10} - 7280 \cdot c^8 + 7160 \cdot c^6 - 1800 \cdot c^4 - 1050 \cdot c^2 + 225}{12288 \cdot s^{10} \cdot (8 \cdot c^4 - 11 \cdot c^2 + 3) \cdot (6 \cdot c^2 - 1)} =$$
= 3.3386 -

C1 $$C_1 = \frac{8 \cdot c^4 - 8 \cdot c^2 + 9}{8 \cdot s^4} =$$ 1.9240 -

$$C_2 = \frac{3840 \cdot c^{12} - 4096 \cdot c^{10} + 2592 \cdot c^8 - 1008 \cdot c^6 + 5944 \cdot c^4 - 1830 \cdot c^2 + 147}{512 \cdot s^{10} \cdot (6 \cdot c^2 - 1)} =$$ 8.9142 -

C3 $$C_3 = -\frac{1}{4 \cdot c \cdot s} =$$ -0.1129 -

C4 $$C_4 = \frac{12 \cdot c^8 + 36 \cdot c^6 - 162 \cdot c^4 + 141 \cdot c^2 - 27}{192 \cdot c \cdot s^9} =$$ 0.1419 -

K1 $$K_1 = \lambda \cdot A_{11} + \lambda^3 \cdot A_{13} + \lambda^5 \cdot A_{15} =$$ 0.1552 -

K2	$K_2 = \lambda^2 \cdot A_{22} + \lambda^4 \cdot A_{24} =$	0.0065	-
K3	$K_3 = \lambda^3 \cdot A_{33} + \lambda^5 \cdot A_{35} =$	0.0001	-
K4	$K_4 = \lambda^4 \cdot A_{44} =$	0.0000	-
K5	$K_5 = \lambda^5 \cdot A_{55} =$	0.0000	-

Project	**: N05-A Pipeline design**
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Horizontal wave particle velocities

Water depth at which data required, z (w.r.t. seabed) 0.5080 m

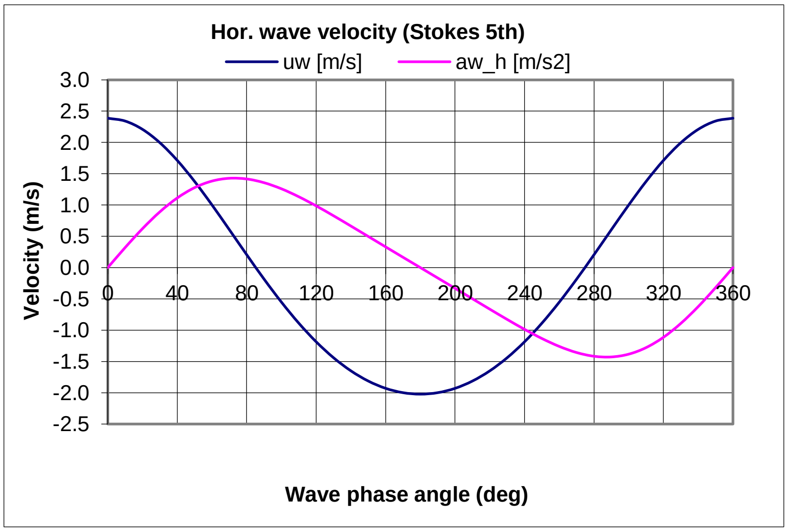
Horizontal velocity, u_w

$$u_w = \frac{L}{T} \cdot \sum_{n=1}^{5} n \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \cos(n \cdot \varphi)$$

Horizontal acceleration, $a_{w,h}$

$$a_{w,h} = \frac{2 \cdot \pi \cdot L}{T^2} \cdot \sum_{n=1}^{5} n^2 \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \sin(n \cdot \varphi)$$

ϕ [deg.]	uw [m/s]	aw_h [m/s^2]
0.00	2.3878	0.0000
10.00	2.3427	0.3202
20.00	2.2098	0.6227
30.00	1.9965	0.8913
40.00	1.7141	1.1129
50.00	1.3773	1.2783
60.00	1.0025	1.3832
70.00	0.6068	1.4278
80.00	0.2066	1.4167
90.00	-0.1836	1.3575
100.00	-0.5515	1.2596
110.00	-0.8877	1.1329
120.00	-1.1853	0.9867
130.00	-1.4402	0.8286
140.00	-1.6498	0.6646
150.00	-1.8129	0.4982
160.00	-1.9293	0.3316
170.00	-1.9990	0.1655
180.00	-2.0222	0.0000
190.00	-1.9990	-0.1655
200.00	-1.9293	-0.3316



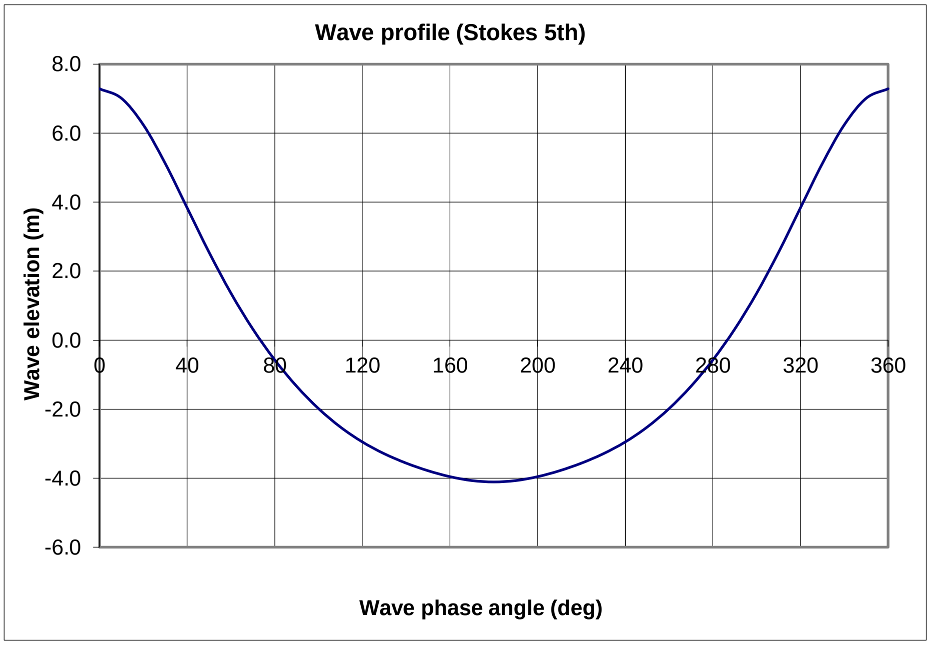
210.00	-1.8129	-0.4982
220.00	-1.6498	-0.6646
230.00	-1.4402	-0.8286
240.00	-1.1853	-0.9867
250.00	-0.8877	-1.1329
260.00	-0.5515	-1.2596
270.00	-0.1836	-1.3575
280.00	0.2066	-1.4167
290.00	0.6068	-1.4278
300.00	1.0025	-1.3832
310.00	1.3773	-1.2783
320.00	1.7141	-1.1129
330.00	1.9965	-0.8913
340.00	2.2098	-0.6227
350.00	2.3427	-0.3202
360.00	2.3878	0.0000

U_{wm} = max. wave particle velocity = 2.39 m/s

Wave profile h(t)

$$\eta(t)=\frac{L}{2\cdot\pi}\left\{\lambda\cdot\cos(\varphi)+\left(\lambda^2\cdot B_{22}+\lambda^4\cdot B_{24}\right)\cdot\cos(2\varphi)+\left(\lambda^3\cdot B_{33}+\lambda^5\cdot B_{35}\right)\cdot\cos(3\varphi)+\lambda^4\cdot B_{44}\cdot\cos(4\varphi)+\lambda^5\cdot B_{55}\cdot\cos(5\varphi)\right\}$$

φ (deg.)	η(t) (m)
0.00	7.2865
10.00	7.0115
20.00	6.2418
30.00	5.1225
40.00	3.8366
50.00	2.5478
60.00	1.3619
70.00	0.3219
80.00	-0.5728
90.00	-1.3376
100.00	-1.9847
110.00	-2.5198
120.00	-2.9504
130.00	-3.2916
140.00	-3.5642
150.00	-3.7849
160.00	-3.9567
170.00	-4.0697
180.00	-4.1095
190.00	-4.0697
200.00	-3.9567
210.00	-3.7849
220.00	-3.5642
230.00	-3.2916
240.00	-2.9504
250.00	-2.5198
260.00	-1.9847
270.00	-1.3376
280.00	-0.5728
290.00	0.3219
300.00	1.3619
310.00	2.5478
320.00	3.8366
330.00	5.1225
340.00	6.2418
350.00	7.0115
360.00	7.2865



Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Operational

Situation 4 Operational

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Material		=	L360NB	
Design temperature		T_d =	50	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	$m/m/^oC$
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Operational		96.1	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	2636.6	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	11.5	m LAT
Minimum water depth		WD_{min} =	8	m LAT
Other water depth (to be used for calculations)		WD =	8	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.14	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-0.78	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	7.22	m LAT
Highest Astronomical Tide		HAT =	3.5	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	5.2	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	7.7	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	6.2	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	8.1	s

Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01003-04-01 - Buckling & Collapse calculations - 8m - operation.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

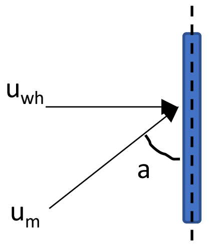
Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$\frac{H_{max}}{g \cdot T_z^2} =$ 0.0096

$\frac{SWL}{g \cdot T_z^2} =$ 0.0112

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th



	Wave particle velocity from metocean data		
Maximum wave particle velocity	u_{wm} =	1.60	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	1.60	m/s

Current:

Height above seabed at which velocity is known	z* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.89	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	1	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.12	m/s
Current velocity at reference height	U_{czr} =	1.12	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.89	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 1372 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e) \cdot (p_c^2 - p_p^2) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}}$ = 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT$ = 18.1 m

0.181 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.19 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **= OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-

$n = 1 + 300 \cdot d_{nom} / OD_g$ n = 13.6 -

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 1.001E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,** q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws = 389 N/m

$F_D + F_I$ =	1372	N/m
g_w =	1.1	-
g_h =	1.2	-

Table 3 - NEN3656

q = 1700 N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.00E+06 N·m

Maximum span length, L_{max} = 76.7 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT = 46 -

R_e = 360.00 N/mm^2

R_{ed} = 360.00 N/mm^2

$$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$$

s_p = 169.3 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0005 < 0.0030 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p = 1.15 -

g_t = 1.1 -

N = -2.05E+06 N

$L_{max,bb}$ = 61.7 m

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Installation: filled

Situation — 2 — Installation: filled

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	:	**N05-A Pipeline design**
Project #	:	19018
Subject	:	Buckling and Collapse
File #	:	19018-60-CAL-01003-05-01 - Buckling & Collapse calculations - 8m - installation flooded.xlsx
Client	:	ONE-Dyas
Client File #	:	19018-60-CAL-01003-05-01 - Buckling & Collapse calculations - 8m - installation flooded.xlsx

Originator	: EvW	Checked :
Date	: 27/01/2020	
Revision	: 01	

Material			=	L360NB	
Design temperature		T_d	=	15	°C
Yield at ambient temperature		R_e	=	360.00	N/mm^2
Yield at design temperature		R_{ed}	=	360.00	N/mm^2
Density		ρ_{st}	=	7850	kg/m^3
Youngs modulus		E_s	=	210000	N/mm^2
Poisson's ratio		u	=	0.3	-
Linear thermal expansion coefficient		a	=	1.16E-05	$m/m/^oC$
Contents					
Sea water density				1025	kg/m^3
Pipeline product density				96.1	kg/m^3
Pipeline content density used for this case:	Installation: filled			1025	kg/m^3
Pipeline Weights					
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$	=	4195.8	N/m
Piggyback weight in air		$W_{pg,a}$	=	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$	=	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$	=	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$	=	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$	=	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$	=	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$	=	2109.4	N/m
Soil					
Submerged density		ρ_{ss}	=	1000	kg/m^3
Depth of burial		d_b	=	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres}	=	0.008	N/mm^2
Environmental conditions					
Water depths:					
Seawater density		ρ_{sw}	=	1025	kg/m3
Maximum water depth		WD_{max}	=	11.5	m LAT
Minimum water depth		WD_{min}	=	8	m LAT
Other water depth (to be used for calculations)		WD	=	8	m LAT
Storm surge, RP1 yr		ss_{1yr}	=	-0.14	m LAT
Storm surge, RP100 yr		ss_{100yr}	=	-0.78	m LAT
Storm surge water level	SSWL = WD + ss	SSWL	=	7.86	m LAT
Highest Astronomical Tide		HAT	=	3.5	m
Waves (H_{max} & T_{max}):					
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$	=	5.2	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$	=	7.7	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$	=	6.2	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$	=	8.1	s

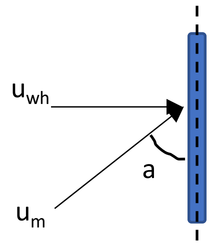
Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$\frac{H_{max}}{g \cdot T_z^2} =$ 0.0089

$\frac{SWL}{g \cdot T_z^2} =$ 0.0135

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th



Wave particle velocity from metocean data

Maximum wave particle velocity	u_{wm} =	1.30	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	1.30	m/s

Current:

Height above seabed at which velocity is known	z* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.89	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	1	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.12	m/s
Current velocity at reference height	U_{czr} =	0.89	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.71	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 891 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e)\cdot(p_c^2 - p_p^2) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3 =$ 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}} =$ 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT =$ 18.1 m

0.181 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres} =$ 0.19 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \le \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \le \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **= OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \le \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \le \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-
$n = 1 + 300 \cdot d_{nom} / OD_g$ n =	13.6	-

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 1.001E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,**

q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws =	2109	N/m
$F_D + F_I$ =	891	N/m
g_w =	1.1	-
g_h =	1.2	-
Table 3 - NEN3656		
q =	2555	N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.00E+06 N·m

Maximum span length, L_{max} = 62.6 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT = 11 -

R_e = 360.00 N/mm^2

R_{ed} = 360.00 N/mm^2

$$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$$

s_p = 3.1 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0001 < 0.0033 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p = 1.15 -

g_t = 1.1 -

N = -8.97E+05 N

$L_{max,bb}$ = 93.1 m

Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-06-01 - Buckling & Collapse calculations - 8m - hydrotest.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01003-06-01 - Buckling & Collapse calculations - 8m - hydrotest.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Hydrotest

Situation 3 Hydrotest

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

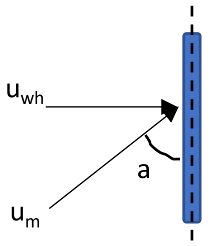
Material		=	L360NB	
Design temperature		T_d =	15	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	$m/m/^oC$
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Hydrotest		1025	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	4195.8	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	11.5	m LAT
Minimum water depth		WD_{min} =	8	m LAT
Other water depth (to be used for calculations)		WD =	8	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.14	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-0.78	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	7.86	m LAT
Highest Astronomical Tide		HAT =	3.5	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	5.2	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	7.7	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	6.2	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	8.1	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$\frac{H_{max}}{g\cdot T_z^2} =$ 0.0089

$\frac{SWL}{g\cdot T_z^2} =$ 0.0135

Wave theory selected:
1. Airy/linear wave; 2. Stokes 5th



Wave particle velocity from metocean data

Maximum wave particle velocity	u_{wm} =	1.30	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	1.30	m/s

Current:

Height above seabed at which velocity is known	z^* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.89	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	1	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.12	m/s
Current velocity at reference height	U_{czr} =	0.89	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\quad \frac{7}{8}\cdot U_{czr}\cdot\left(\frac{OD_{nom}}{z_r}\right)^{1/7}\cdot\sin(\alpha_{uc}) =$	u_{ch} =	0.71	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 891 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e)\cdot\left(p_c^2 - p_p^2\right) = p_c\cdot p_e\cdot p_p\cdot 2\cdot\delta_o\cdot\frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm^2

External plastic pipe collapse pressure (P_p): $P_p = \frac{2\,R_e\,d_{nom}}{OD_{nom}}$ = 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5\cdot H_{max,100} + HAT$ = 18.1 m
0.181 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.19 N/mm^2

enersea

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ = **OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-
$n = 1 + 300 \cdot d_{nom} / OD_g$ n =	13.6	-

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 1.001E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,**

q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws =	2109	N/m
$F_D + F_I$ =	891	N/m
g_w =	1.1	-
g_h =	1.2	-
Table 3 - NEN3656		
q =	2555	N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.00E+06 N·m

Maximum span length, L_{max} = 62.6 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT =	11	-
R_e =	360.00	N/mm^2
R_{ed} =	360.00	N/mm^2
$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$ s_p =	219.6	N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0001 < 0.0028 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p =	1.15	-
g_t =	1.1	-
N =	1.46E+06	N

$L_{max,bb}$ =	**No compressive force**	**m**

Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-07-01 - Buckling & Collapse calculations - 17m - operation.xlsx
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01003-07-01 - Buckling & Collapse calculations - 17m - operation.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Operational

Situation

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

4
Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Material		=	L360NB	
Design temperature		T_d =	50	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	m/m/°C
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Operational		96.1	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	2636.6	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	20.6	m LAT
Minimum water depth		WD_{min} =	17	m LAT
Other water depth (to be used for calculations)		WD =	17	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.58	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.29	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	15.72	m LAT
Highest Astronomical Tide		HAT =	3.11	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	8.3	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	8.9	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	11.55	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	9.8	s

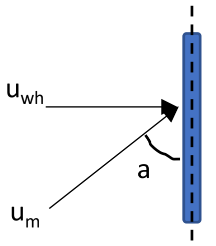
Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

$\frac{H_{max}}{g \cdot T_z^2} =$ 0.0123

$\frac{SWL}{g \cdot T_z^2} =$ 0.0167

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th



Wave particle velocity from interpolated data

Maximum wave particle velocity	u_{wm} =	2.80	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	2.80	m/s

Current:

Height above seabed at which velocity is known	z* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.82	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.92	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.04	m/s
Current velocity at reference height	U_{czr} =	1.04	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.83	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 2909 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by: $$(p_c - p_e)\cdot\left(p_c^2 - p_p^2\right) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm²

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}}$ = 29.2 N/mm²

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm²

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT$ = 29.485 m

0.29485 N/mm²

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.30 N/mm²

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -

g_M = 0.93 -

$g_{m,p}$ = 1.45 -

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ = **OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ = 1.1 -

g_M = 1 -

$g_{m,M}$ = 1.3 -

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm

= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -

$g_{g,M}$ = 1.55 -

$g_{m,p}$ = 1.25 -

$g_{m,M}$ = 1.15 -

g_M = 0.93 -

$n = 1 + 300 \cdot d_{nom} / OD_g$ n = 13.6 -

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm

= 1.000E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,**

q = load acting on pipe

L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws = 389 N/m

$F_D + F_I$ = 2909 N/m

g_w = 1.1 -

g_h = 1.2 -

Table 3 - NEN3656

q = 3517 N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.00E+06 N·m

Maximum span length, L_{max} = 53.3 m

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT	=	46	-
R_e	=	360.00	N/mm^2
R_{ed}	=	360.00	N/mm^2
$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$ s_p	=	169.3	N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \leq \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0005 < 0.0030 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p	=	1.15	-
g_t	=	1.1	-
N	=	-2.05E+06	N
$L_{max,bb}$	=	**61.7**	**m**

Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Installation: filled

Situation

2
Installation: filled

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	: **N05-A Pipeline design**	
Project #	: 19018	
Subject	: Buckling and Collapse	
File #	: 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx	
Client	: ONE-Dyas	
Client File #	: 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx	

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Material		=	L360NB	
Design temperature		T_d =	15	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	$m/m/^oC$
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Installation: filled		1025	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	4195.8	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	20.6	m LAT
Minimum water depth		WD_{min} =	17	m LAT
Other water depth (to be used for calculations)		WD =	17	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.58	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.29	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	16.42	m LAT
Highest Astronomical Tide		HAT =	3.11	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	8.3	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	8.9	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	11.55	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	9.8	s

Project : **N05-A Pipeline design**
Project # : 19018
Subject : Buckling and Collapse
File # : 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx

Client : ONE-Dyas
Client File # : 19018-60-CAL-01003-08-01 - Buckling & Collapse calculations - 17m - installation flooded.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

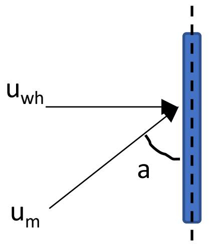
$$\frac{H_{max}}{g \cdot T_z^2} = 0.0107$$

$$\frac{SWL}{g \cdot T_z^2} = 0.0211$$

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th

Wave particle velocity from interpolated data



Maximum wave particle velocity	u_{wm} =	1.85	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	1.85	m/s

Current:

Height above seabed at which velocity is known	z^* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.82	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.92	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.04	m/s
Current velocity at reference height	U_{czr} =	0.82	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.65	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 1380 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e) \cdot (p_c^2 - p_p^2) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}}$ = 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT$ = 29.485 m

0.29485 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.30 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -
g_M = 0.93 -
$g_{m,p}$ = 1.45 -

Assessment: $\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **= OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \frac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ = 1.1 -
g_M = 1 -
$g_{m,M}$ = 1.3 -

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\frac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ = 1.05 -
$g_{g,M}$ = 1.55 -
$g_{m,p}$ = 1.25 -
$g_{m,M}$ = 1.15 -
g_M = 0.93 -
$n = 1 + 300 \cdot d_{nom} / OD_g$ n = 13.6 -

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 1.000E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \frac{q \cdot L^2}{10}$ **Where,**

q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws = 2109 N/m
$F_D + F_I$ = 1380 N/m
g_w = 1.1 -
g_h = 1.2 -
Table 3 - NEN3656
q = 2851 N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.00E+06 N·m

Maximum span length, L_{max} = 59.2 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \le \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT = 11 -

R_e = 360.00 N/mm^2

R_{ed} = 360.00 N/mm^2

$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$ s_p = 3.1 N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \le \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E} \sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0001 < 0.0033 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ Table 3 - NEN3656 - BC4

g_p = 1.15 -

g_t = 1.1 -

N = -8.97E+05 N

$L_{max,bb}$ = 93.1 m

Project	**: N05-A Pipeline design**
Project #	: 19018
Subject	: Buckling and Collapse
File #	: 19018-60-CAL-01003-09-01 - Buckling & Collapse calculations - 17m - hydrotest.xlsx
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01003-09-01 - Buckling & Collapse calculations - 17m - hydrotest.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Buckling and Collapse - 20in x 20.62mm - Hydrotest

Situation

3

Hydrotest

1. Installation: empty
2. Installation: filled
3. Hydrotest
4. Operational

	Pressure (barg)	Temperature (deg. C)
Installation (P_{in}, T_{in})	2	15
Design (P_d, T_d)	111	50
Hydrotest (P_t, T_t)	144	15

Pipeline properties

Nominal diameter		OD_{nom} =	20	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Max. OD deviation	$OD_{max,dev} = 0.35 \cdot d_{min}$	$OD_{max,dev}$ =	7.22	mm
Min. OD deviation	$OD_{min,dev} = 0.35 \cdot d_{min}$	$OD_{min,dev}$ =	7.22	mm
Max. ovalised diameter	$OD_{max} = OD_{nom} + 0.35 \cdot dmin$	OD_{max} =	515.217	mm
Min. ovalised diameter	$OD_{min} = OD_{nom} - 0.35 \cdot dmin$	OD_{min} =	500.783	mm
Initial ovalisation	$\delta_0 = \frac{OD_{max} - OD_{min}}{OD_{max} + OD_{min}}$	d_0 =	0.014	-
Cross sectional area of steel		A =	31572	mm^2
Moment of Inertia		I =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Project	**:**	**N05-A Pipeline design**
Project #	**:**	19018
Subject	**:**	Buckling and Collapse
File #	**:**	19018-60-CAL-01003-09-01 - Buckling & Collapse calculations - 17m - hydrotest.xlsx
Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01003-09-01 - Buckling & Collapse calculations - 17m - hydrotest.xlsx

Originator	: EvW	Checked	:
Date	: 27/01/2020		
Revision	: 01		

Material		=	L360NB	
Design temperature		T_d =	15	°C
Yield at ambient temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m^3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		u =	0.3	-
Linear thermal expansion coefficient		a =	1.16E-05	$m/m/^oC$
Contents				
Sea water density			1025	kg/m^3
Pipeline product density			96.1	kg/m^3
Pipeline content density used for this case:	Hydrotest		1025	kg/m^3
Pipeline Weights				
Pipeline weight in air	$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$	$W_{pl,a}$ =	4195.8	N/m
Piggyback weight in air		$W_{pg,a}$ =	0.0	N/m
Buoyancy force pipeline	$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$	$F_{B,pl}$ =	2086.5	N/m
Buoyancy force piggyback		$F_{B,pb}$ =	0.0	N/m
Submerged pipeline weight,empty		$W_{pl,s,e}$ =	388.8	N/m
Submerged piggyback weight		$W_{pg,s}$ =	0.0	N/m
Total submerged bundle weight,empty		$W_{T,s,e}$ =	388.8	N/m
Total submerged bundle weight,water filled		$W_{T,s,f}$ =	2109.4	N/m
Soil				
Submerged density		ρ_{ss} =	1000	kg/m^3
Depth of burial		d_b =	0.80	m
Soil cover pressure	$SC_{pres} = r_{ss} \times d_b \times g$	SC_{pres} =	0.008	N/mm^2
Environmental conditions				
Water depths:				
Seawater density		ρ_{sw} =	1025	kg/m3
Maximum water depth		WD_{max} =	20.6	m LAT
Minimum water depth		WD_{min} =	17	m LAT
Other water depth (to be used for calculations)		WD =	17	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.58	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.29	m LAT
Storm surge water level	SSWL = WD + ss	SSWL =	16.42	m LAT
Highest Astronomical Tide		HAT =	3.11	m
Waves (H_{max} & T_{max}):				
Maximum wave height, RP1 yr - installation/hydrotes		$H_{max,1}$ =	8.3	m
Associated maximum wave period, RP1 yr		$T_{ass,1}$ =	8.9	s
Maximum wave height, RP100 yr - operational		$H_{max,100}$ =	11.55	m
Associated maximum wave period, RP100 yr		$T_{ass,100}$ =	9.8	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

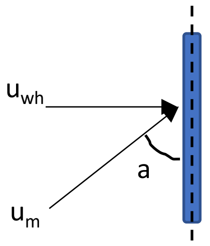
$$\frac{H_{max}}{g \cdot T_z^2} = \quad 0.0107$$

$$\frac{SWL}{g \cdot T_z^2} = \quad 0.0211$$

Wave theory selected:

1. Airy/linear wave; 2. Stokes 5th

Wave particle velocity from interpolated data



Maximum wave particle velocity	u_{wm} =	1.85	m/s
Angle of attack relative to pipeline axis	α_{uw} =	90	deg
Horizontal wave velocity ⊥ to P/L	u_{wh} =	1.85	m/s

Current:

Height above seabed at which velocity is known	z^* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.82	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.92	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.04	m/s
Current velocity at reference height	U_{czr} =	0.82	m/s
Angle of attack relative to pipeline axis	α_{uc} =	90	deg
Horizontal current velocity ⊥ to P/L $\quad \frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc}) =$	u_{ch} =	0.65	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Maximum absolute hydrodynamic force 1380 N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Collapse - external pressure only (K.3.3.5.1)

External implosion pipe collapse pressure (P_c) given by:

$$(p_c - p_e) \cdot (p_c^2 - p_p^2) = p_c \cdot p_e \cdot p_p \cdot 2 \cdot \delta_o \cdot \frac{OD_g}{d_{nom}}$$

External elastical pipe collapse pressure (P_e): $P_e = \frac{2E_s}{1-\nu^2}\left(\frac{d_{nom}}{OD_{av}}\right)^3$ = 34.0 N/mm^2

External plastic pipe collapse pressure (P_p) $P_p = \frac{2 R_e d_{nom}}{OD_{nom}}$ = 29.2 N/mm^2

External implosion pipe collapse pressure (P_c): P_c = 16.0 N/mm^2

Maximum water column above mudline (WC_{max}) $WC_{max} = WD_{max} + 0.5 \cdot H_{max,100} + HAT$ = 29.485 m

0.29485 N/mm^2

Actual external pressure (P_L) $WC_{max} + SC_{pres}$ = 0.30 N/mm^2

Assessment: $\gamma_{g,p} \cdot P_L \leq \dfrac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
g_M =	0.93	-
$g_{m,p}$ =	1.45	-

Assessment: $\gamma_{g,p} \cdot P_L \leq \dfrac{\gamma_M \cdot P_c}{\gamma_{m,p}}$ = **OK**

Collapse - bending moment only (K.3.3.5.2)

Buckling bending moment (M_c) $M_c = D_g^2 d_n R_e$ = 1.8E+09 N·mm

Assessment: $\gamma_{g,M} \times M_L \leq \dfrac{\gamma_M \times M_c}{\gamma_{m,M}}$ **Where,**

Table 4 - NEN3656

$g_{g,M}$ =	1.1	-
g_M =	1	-
$g_{m,M}$ =	1.3	-

Maximum allowable bending moment ($M_{L,b}$) $M_{L,b}$ = 1.3E+09 N·mm
= 1.256E+06 N·m

Collapse - external pressure + bending moment only (K.3.3.5.3)

Assessment: $\dfrac{\gamma_{g,p} \times P_L}{P_c / \gamma_{m,p}} + \left(\dfrac{\gamma_{g,M} \times M_L}{M_c / \gamma_{m,M}}\right)^n \leq \gamma_M$ **Where,**

Table 4 - NEN3656

$g_{g,p}$ =	1.05	-
$g_{g,M}$ =	1.55	-
$g_{m,p}$ =	1.25	-
$g_{m,M}$ =	1.15	-
g_M =	0.93	-

$n = 1 + 300 \cdot d_{nom} / OD_g$ n = 13.6 -

Maximum allowable bending moment ($M_{L,pb}$) $M_{L,pb}$ = 1.0E+09 N·mm
= 1.000E+06 N·m

Determination maximum span length due to bending only or bending & external pressure

Assessment: $M_{L,m} = \dfrac{q \cdot L^2}{10}$ **Where,** q = load acting on pipe
L = span length

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Ws = submerged pipeline weight; Ws = 2109 N/m
$F_D + F_I$ = 1380 N/m

g_w =	1.1	-
g_h =	1.2	-

Table 3 - NEN3656
q = 2851 N/m

Maximum allowable bending moment ($M_{L,m}$) is smallest of $M_{L,b}$ and $M_{L,pb}$ $M_{L,m}$ = 1.000E+06 N·m

Maximum span length, L_{max} = 59.2 m

Progressive plastic collapse (K.3.3.6)

Assessment: $\varepsilon_{max} = \alpha \times \Delta T \le \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$

Temperature difference with ambient; DT =	11	-
R_e =	360.00	N/mm^2
R_{ed} =	360.00	N/mm^2
$\sigma_p = \frac{p \cdot (OD_{nom} - d_{min})}{2 \cdot d_{min}}$ — s_p =	219.6	N/mm^2

$$\varepsilon_{max} = \alpha \times \Delta T \le \left[\frac{R_e(\theta)}{E} \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_p}{R_e}\right)^2} \right]$$

Assessment: 0.0001 < 0.0028 **OK**

Local buckling (K.3.3.3)

Assessment: $\frac{(OD_{nom} - d_{min})}{d_{nom}} < 55$: no check on local buckling required = 23.9 **OK**

Bar buckling:

Assessment: $L_{max,bb} = \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$

Effective axial force $N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$

$S_h = g_p \cdot s_h$ — Table 3 - NEN3656 - BC4

g_p =	1.15	-
g_t =	1.1	-
N =	1.46E+06	N

$L_{max,bb}$ =	**No compressive force**	**m**

C. Static and Dynamic Span Analysis

The following static and dynamic span analyses were performed:

- 19018-60-CAL-01004-01-01 Allowable free span (static & dynamic) calculations -26m
- 19018-60-CAL-01004-02-01 Allowable free span (static & dynamic) calculations -8m
- 19018-60-CAL-01004-03-01 Allowable free span (static & dynamic) calculations -17m

(25pages)

Project	**: N05-A Pipeline Design**
Project #	: 19018
Subject	: Static & Dynamic Span Analysis
File #	: 19018-60-CAL-01004-01-01 - Allowable free span (static & dynamic) calculations - 26m.xlsm
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01004-01-01 - Allowable free span (static & dynamic) calculations - 26m.xlsm

Originator	: EvW	Checked	: PF
Date	: 24/01/2020		
Revision	: 01		

Static & Dynamic Span - 20" x 20.62 mm

Condition Overview

	Pressure (barg)	Temp. (deg. C)	Content (kg/m3)
Installation (P_{in}, T_{in})	2	15	1025
Hydrotest (P_t, T_t)	144	15	1025
Design (P_d, T_d)	111	50	88.7

Pipeline properties

Nominal diameter		OD_{nom} =	20"	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Internal diameter	$ID = OD_{nom} - 2 \cdot d_{nom}$	ID =	466.76	mm
Cross sectional area of steel	$A_s = \frac{\pi}{4} \cdot \{OD_{nom}^2 - ID^2\}$	A_s =	31572	mm^2
Section modulus	$W_s = \frac{\pi}{32} \cdot \frac{\{OD_{nom}^4 - ID^4\}}{OD_{nom}}$	W_s =	3697384	mm^3
Moment of Inertia	$I_s = \frac{\pi}{64} \cdot \{OD_{nom}^4 - ID^4\}$	I_s =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback			
Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating and insulation data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Material

	=	L360NB	
Design temperature	T_d =	50	°C
Yield at ambient/hydrotest temperature	R_e =	360.00	N/mm^2
Yield at design temperature	R_{ed} =	360.00	N/mm^2
Density	ρ_{st} =	7850	kg/m3
Youngs modulus	E_s =	210000	N/mm^2
Poisson's ratio	u =	0.3	-
Linear thermal expansion coefficient	a =	1.16E-05	m/m/°C

Weights

		installation (N/m)	hydrotest (N/m)	operation (N/m)
air	line pipe	2431.3	2431.3	2431.3
	content	1720.6	1720.6	148.9
	coating	43.9	43.9	43.9
	piggyback	0.0	0.0	0.0
	coating pb	0.0	0.0	0.0
buoyancy	line pipe	2086.5	2086.5	2086.5
	piggyback	0.0	0.0	0.0

$$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$$

$$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$$

Static & Dynamic span to be checked for the following environmental load combinations

Condition	Wave velocity	Current velocity	Comment
Installation	$H_{max,1yr}$	1 yr	
Hydrotest	$H_{max,1yr}$	1 yr	
Operational	$H_{max,100yr}$	10 yr	LC1
	$H_{max,10yr}$	100 yr	LC2

Environmental conditions

Water depths:

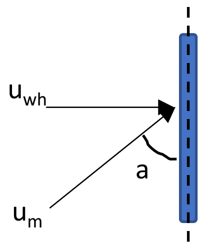
Seawater density		ρ_{sw} =	1025	kg/m^3
Maximum water depth		WD_{max} =	29.68	m LAT
Minimum water depth		WD_{min} =	26	m LAT
Other water depth (user input)		WD =	26	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-1.02	m LAT
Storm surge, RP10 yr		ss_{10yr} =	-1.4	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.79	m LAT
Storm surge water level, RP1 yr	$SSWL_{1yr} = WD + ss_{1yr}$	$SSWL_{1yr}$ =	24.98	m LAT
Storm surge water level, RP10 yr	$SSWL_{10yr} = WD + ss_{10yr}$	$SSWL_{10yr}$ =	24.6	m LAT
Storm surge water level, RP100 yr	$SSWL_{100yr} = WD + ss_{100yr}$	$SSWL_{100yr}$ =	24.21	m LAT
Highest Astronomical Tide		HAT =	2.72	m

Waves (H_{max} & T_{max}):

Maximum wave height, RP1 yr - installation/hydrotest	$H_{max,1}$ =	11.4	m
Associated maximum wave period, RP1 yr	$T_{ass,1}$ =	10.1	s
Maximum wave height, RP10 yr - operational	$H_{max,10}$ =	14.5	m
Associated maximum wave period, RP10 yr	$T_{ass,10}$ =	10.9	s
Maximum wave height, RP100 yr - operational	$H_{max,100}$ =	16.9	m
Associated maximum wave period, RP100 yr	$T_{ass,100}$ =	11.5	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0114	0.0124	0.0130
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0250	0.0211	0.0187
theory	Stokes	Stokes	Stokes
maximum wave particle velocity (u_{wm})	2.39	3.26	4.00
angle of attack relative to P/L axis (a)	90	90	90
horizontal wave velocity ⊥ to P/L (u_{wh})	2.39	3.26	4.00



Current:

Height above seabed at which velocity is known	z* =	2	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.74	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.84	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	0.96	m/s

Current velocity at reference height: $U_{czr} = u_{st} + u_{ss}$

$U_{czr,1}$ = 0.74 m/s
$U_{czr,10}$ = 0.84 m/s
$U_{czr,100}$ = 0.96 m/s

Angle of attack relative to pipeline axis α_{uc} = 90 deg

Horizontal current velocity ⊥ to P/L:

$$u_{cm,perp} = \frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc})$$

$u_{cm,perp,1}$ = 0.532 m/s
$u_{cm,perp,10}$ = 0.604 m/s
$u_{cm,perp,100}$ = 0.691 m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Hydrodunamic forces:

Maximum absolute hydrodynamic force (F_D+F_I), RP1 yr (installation/hydrotest condition)	1824	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP100/10 yr (LC 1 operational condition)	4175	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP10/100 yr (LC 2operational condition)	3124	N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Table 3 - NEN 3656 load factors

Load factor	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
Self weight & content	1.1	1.1	1.1	1.1	
Coating	1.2	1.2	1.2	1.2	
Marine growth	0	0	1.2	1.2	
Internal pressure	0	1.15	1.15	1.15	
external pressure	1.1	1.1	1.1	1.1	
temperature	1	1.1	1.1	1.1	
environmental load	1.1	1.2	1.2	1.2	
Pipe bundle weight in air	4619.8	4619.8	2891.0	2891.0	N/m; incl. load factors
Submerged bundle weight, Ws	2324.7	2324.7	595.9	595.9	N/m; incl. load factors
Factored load acting on pipe, q	3071	3193	5045	3796	N/m; $q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$
Pressure	2	144	111	111	barg
DT	11	11	46	46	deg. C
Material factor (table 3; D3.1)	1.1	1.1	1.1	1.1	
Allowable stress (table 3; D3.1)	327.3	556.4	556.4	556.4	N/mm^2

STATIC SPAN LENGTH - INSTALLATION

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression		
Hoop stress	4.4	4.4	4.4	4.4	N/mm^2	$\sigma_H = \frac{(\gamma i \cdot Pi - \gamma e \cdot Pe) \cdot (OD - d_{min})}{2 \cdot d_{min}}$
Max. long. Stress	329.4	-325.1	329.4	-325.1	N/mm^2	$\sigma_{max.long.stress} = \frac{\sigma_H \pm \sqrt{-3 \cdot \sigma_H^2 + 4 \cdot \sigma_{allow}^2}}{2}$
Long. hoop stress	1.8	1.8	1.3	1.3	N/mm^2	$\sigma_{long.hoop.stress} = v \cdot \sigma_H$
Thermal exp. stress	n/a	n/a	-26.8	-26.8	N/mm^2	$\sigma_{thermal} = -\gamma_t \cdot \alpha \cdot E_s \cdot \Delta T$
Max. allow. bending stress	327.3	-326.8	327.3	-299.6	N/mm^2	$\sigma_{b,max} = \sigma_{max.long.stress} - \sigma_{lonh.hoop.stress} - \sigma_{thermal}$
Maximum span	62.8	62.7	62.8	60.1	m	

STATIC SPAN LENGTH - HYDROTEST

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression	
Hoop stress	248.2	248.2	248.2	248.2	N/mm^2
Max. long. Stress	637.3	-389.1	637.3	-389.1	N/mm^2
Long. hoop stress	85.8	85.8	74.5	74.5	N/mm^2
Thermal exp. stress	n/a	n/a	-29.5	-29.5	N/mm^2
Max. allow. bending stress	551.4	-474.9	556.4	-434.0	N/mm^2
Maximum span	79.9	74.2	80.3	70.9	m

STATIC SPAN LENGTH - OPERATION LC1

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression	
Hoop stress	190.3	190.3	190.3	190.3	N/mm^2
Max. long. Stress	626.6	-436.2	626.6	-436.2	N/mm^2
Long. hoop stress	66.2	66.2	57.1	57.1	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-502.4	556.4	-370.1	N/mm^2
Maximum span	63.9	60.7	63.9	52.1	m

STATIC SPAN LENGTH - OPERATION LC2

	Unrestrained pipe		Restrained pipe		
	tension	compression	tension	compression	
Hoop stress	190.3	190.3	190.3	190.3	N/mm^2
Max. long. Stress	626.6	-436.2	626.6	-436.2	N/mm^2
Long. hoop stress	66.2	66.2	57.1	57.1	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-502.4	556.4	-370.1	N/mm^2
Maximum span	73.6	70.0	73.6	60.0	m

DYNAMIC SPAN ANALYSIS (NEN 3656 - I.5.2.5)

Assessment

Stability parameter, Ks < 1.8 => in-line vibration
Stability parameter, Ks < 16 => cross flow vibration

$$K_s = \frac{2m \times \delta}{\rho_w \times D_o^2}$$

Where,

d = damping factor water: 0.02 x 2 x π	=	0.126	-
r_w = seawater density	=	1025	kg/m³
D_o = outer diameter (incl. coating)	=	514	mm
m = effective mass			
m = W_{bundle} + M_{added}			
$M_{added} = \frac{\pi}{4} \cdot C_m \cdot \rho_w \cdot D_{o,eq}^2$			
C_m = added mass coefficient	=	1.2	-
$D_{o,eq}$ = equivalent diameter (incl. coating)	=	514	mm

Due to the presense of 2 objects attached to eachother, velocity flow intensification occurs:

$v_{tot} = (v_{wave} + v_{cur}) \times (1 + f_{int})$;

$$f_{int} = \left\{1 + \left(\frac{D_{ob}^2}{4 \cdot CL^2}\right)\right\}$$

Where,
D_{ob} = diameter of obstruction
CL = centerline distance P/L - obstruction

IN-LINE VIV:

Given the stability factor (Ks), the horizontal particle velocity (v), possibly including vicinity factor and the reduced velocity (Vr), the first eigen frequency (f1) can be determined prior to vibration occurring.

Reduced velocity, Vr, based on NEN 3656 I.5.2.5.2

$$V_r = \frac{v}{f_1 \times D_o}$$

if $1{,}0 \le V_r \le 3{,}5$ then oscillation occurs => Vr<1,0 design criterium

Vr is set to 1 as conservative value; Vr = 1.0 -

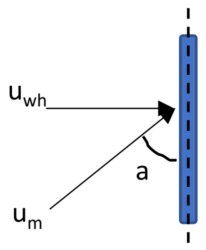
$$f_1 = \frac{a}{2\pi}\sqrt{\frac{E \times I}{m \times L^4}}$$

Where,
a = frequency factor (22 for fixed/fixed; 9.87 for pinned/pinned)
a = 15.4 for fixed/pinned a = 15.4 -

Waves (Hs & Tz):

Significant wave height, RP1 yr - installation/hydrotest	$H_{s,1}$ =	6.5	m
Associated wave period, RP1 yr	$T_{z,1}$ =	9.9	s
Significant wave height, RP10 yr - operational	$H_{s,10}$ =	8.4	m
Associated wave period, RP10 yr	$T_{z,10}$ =	11.3	s
Significant wave height, RP100 yr - operational	$H_{s,100}$ =	9.9	m
Associated wave period, RP100 yr	$T_{z,100}$ =	12.3	s

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0068	0.0067	0.0067
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0260	0.0196	0.0163
theory	Stokes	Stokes	Stokes
maximum wave particle velocity (u_{wm})	1.35	2.01	2.56
angle of attack relative to P/L axis (a)	90	90	90
horizontal wave velocity ⊥ to P/L (u_{wh})	1.35	2.01	2.56



Project	**: N05-A Pipeline Design**
Project #	: 19018
Subject	: Static & Dynamic Span Analysis
File #	: 19018-60-CAL-01004-01-01 - Allowable free span (static & dynamic) calculations - 26m.xlsm
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Originator	: EvW	Checked	: PF
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	Installation	**Hydrotest**	**LC 1 Operation**	**LC 2 Operation**	
effective mass	682.9	682.9	522.7	522.7	kg/m
K_s	0.63	0.63	0.49	0.49	-
In-line VIV	yes	yes	yes	yes	-
cross flow VIV	yes	yes	yes	yes	-
Vr	1.00	1.00	1.00	1.00	-
u_{wh}	0.53	0.53	0.60	0.69	m/s, set equal to Ucm, for velocity ratio 0.5
$u_{cm,perp}$	0.53	0.53	0.60	0.69	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp})$ x $(1+0.5 \cdot f_{int}) = v_{tot}$	1.06	1.06	1.21	1.38	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
f1	2.07	2.07	2.35	2.69	1/s
$L_{span,in}$	25.2	25.2	25.3	23.7	m

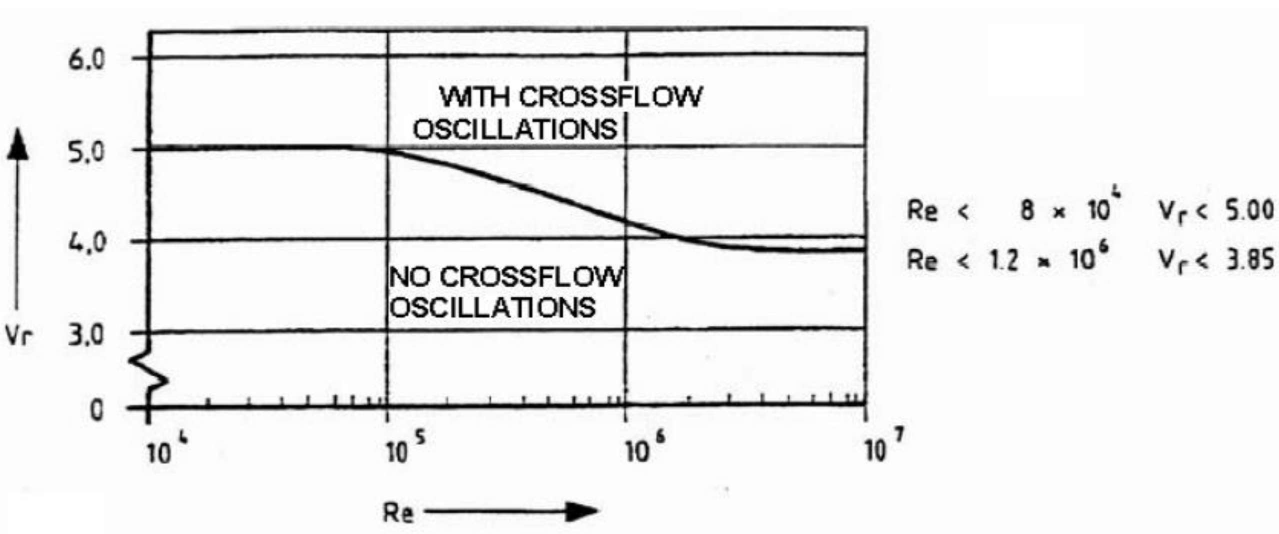
note: f_{int} is taken into account for 50% as system doesn't instantaneously respond and vortices occur in a relatively steady state environment, which this isn't.

CROSS FLOW VIV:

Oscillation area for cross flow is given by the figure below and depends on the Reynolds number (R_e)

$$R_e = \frac{v \cdot D_o}{\nu_d}$$

v = horizontal particle velocity (v_{tot})			
D_o = outer diameter (incl. coating)	=	514	mm
u_d = dynamic viscosity seawater	u_d =	4.99E-07	m^2/s
Vr is set to 3.85 as conservative value;	Vr =	3.85	-



	Installation	**Hydrotest**	**LC 1 Operation**	**LC 2 Operation**	
u_{wh}	1.35	1.35	2.56	2.01	m/s
$u_{cm,perp}$	0.53	0.53	0.60	0.69	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp})$ x $(1+0.5 \cdot f_{int}) = v_{tot}$	1.89	1.89	3.17	2.70	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
Reynolds nr.	1.94E+06	1.94E+06	3.26E+06	2.78E+06	-
Vr	3.850	3.850	3.850	3.850	-
f1	0.95	0.95	1.60	1.36	1/s
$L_{span,cross}$	37.2	37.2	30.7	33.2	m

SUMMARY - SPAN ANALYSIS

	Installation	**Hydrotest**	**LC 1 Operation**	**LC 2 Operation**	
$L_{span,in}$	25.2	25.2	25.3	23.7	m
$L_{span,cross}$	37.2	37.2	30.7	33.2	m

Maximum Span Length = 23.7 m

Originator	: EvW	Checked	: PF
Date	: 24/01/2020		
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Static & Dynamic Span - 10" x 12.7mm

Water depth	WD =	26	m (LAT)
Storm surge	ss =	-1.02	m
Storm surge water level	$SWL = WD + ss$ =	24.98	m
Wave height	H =	11.4	m
Wave period	T =	10.1	s
Grav. Acceleration	g =	9.81	m/s^2
Deep water wave length	$L_o = \frac{g \cdot T^2}{2 \cdot \pi}$ =	159.3	m

Solving for wave length (L) and λ

$$\frac{\pi \cdot H}{SWL} - \frac{L}{SWL}\left\{\lambda + \lambda^3 \cdot B_{33} + \lambda^5 \cdot (B_{35} + B_{55})\right\} = 0 \quad (\text{I})$$

$$\frac{SWL}{L_O} - \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right) \cdot \left\{1 + \lambda^2 \cdot C_1 + \lambda^4 \cdot C_2\right\} = 0 \quad (\text{II})$$

Choosing L and solving for λ in (II) results in 4 roots for λ

Estimate actual wave length, L **143.109** **m**

$A = SWL / L_O$ = 0.1568

$B = \frac{SWL}{L} \cdot \tanh\left(\frac{2 \cdot \pi \cdot SWL}{L}\right)$ = 0.1395

$$\lambda = \pm\sqrt{X}$$

$$X = \frac{-C_1 \cdot B \pm \sqrt{D}}{2 \cdot C_2 \cdot B}$$

$D = (C_1 \cdot B)^2 - 4 \cdot (C_2 \cdot B) \cdot (-(A - B))$ = 0.1583

	-	eq. (I)	eq. (II)
λ1	0.228	-0.0006	0.0000
λ2	Numerator of X < 0		
λ3	-0.228	2.8680	0.0000
λ4	Numerator of X < 0		

Item	Formula	Value	Unit
s	$s = \sinh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.3302	-
c	$c = \cosh\left(\frac{2 \cdot \pi \cdot WL}{L}\right) =$	1.6642	-
A11	$A_{11} = \frac{1}{s} =$	0.7518	-
A13	$A_{13} = \frac{-c^2 \cdot (5 \cdot c^2 + 1)}{8 \cdot s^5} =$	-1.2341	-
	$A_{15} = -\frac{1184 \cdot c^{10} - 1440 \cdot c^8 - 1992 \cdot c^6 + 2641 \cdot c^4 - 249 \cdot c^2 + 18}{1536 \cdot s^{11}} =$	-2.4111	-
A22	$A_{22} = \frac{3}{8 \cdot s^4} =$	0.1198	-
A24	$A_{24} = \frac{192 \cdot c^8 - 424 \cdot c^6 - 312 \cdot c^4 + 480 \cdot c^2 - 17}{768 \cdot s^{10}} =$	0.0907	-
A33	$A_{33} = \frac{13 - 4 \cdot c^2}{64 \cdot s^7} =$	0.0041	-
	$A_{35} = \frac{512 \cdot c^{12} + 4224 \cdot c^{10} - 6800 \cdot c^8 - 12808 \cdot c^6 + 16704 \cdot c^4 - 3154 \cdot c^2 - 107}{4096 \cdot s^{13} \cdot (6 \cdot c^2 - 1)} =$	0.1403	-
A44	$A_{44} = \frac{80 \cdot c^6 - 816 \cdot c^4 + 1338 \cdot c^2 - 197}{1536 \cdot s^{10} \cdot (6 \cdot c^2 - 1)} =$	-0.0025	-

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$$A_{55} = -\frac{2880\cdot c^{10} - 72480\cdot c^{8} + 324000\cdot c^{6} - 432000\cdot c^{4} + 163470\cdot c^{2} - 16245}{61440\cdot s^{11}\cdot(6\cdot c^{2}-1)\cdot(8\cdot c^{4}-11\cdot c^{2}+3)} =$$ -0.0003 -

B22 $$B_{22} = \frac{(2\cdot c^{2}+1)\cdot c}{4\cdot s^{3}} =$$ 1.1558 -

B24 $$B_{24} = \frac{c\cdot(272\cdot c^{8} - 504\cdot c^{6} - 192\cdot c^{4} + 322\cdot c^{2} + 21)}{384\cdot s^{9}} =$$ 1.5738 -

B33 $$B_{33} = \frac{3\cdot(8\cdot c^{6}+1)}{64\cdot s^{6}} =$$ 1.4462 -

$$B_{35} = \frac{88128\cdot c^{14} - 208224\cdot c^{12} + 70848\cdot c^{10} + 54000\cdot c^{8} - 21816\cdot c^{6} + 6264\cdot c^{4} - 54\cdot c^{2} - 81}{12288\cdot s^{12}\cdot(6\cdot c^{2}-1)} =$$
= 5.1741 -

B44 $$B_{44} = c\cdot\frac{768\cdot c^{10} - 488\cdot c^{8} - 48\cdot c^{6} + 48\cdot c^{4} + 106\cdot c^{2} - 21}{384\cdot s^{9}\cdot(6\cdot c^{2}-1)} =$$ 2.0437 -

$$B_{55} = \frac{192000\cdot c^{16} - 26720\cdot c^{14} + 83680\cdot c^{12} + 20160\cdot c^{10} - 7280\cdot c^{8} + 7160\cdot c^{6} - 1800\cdot c^{4} - 1050\cdot c^{2} + 225}{12288\cdot s^{10}\cdot(8\cdot c^{4}-11\cdot c^{2}+3)\cdot(6\cdot c^{2}-1)} =$$
= 3.3404 -

C1 $$C_{1} = \frac{8\cdot c^{4} - 8\cdot c^{2} + 9}{8\cdot s^{4}} =$$ 1.9244 -

$$C_{2} = \frac{3840\cdot c^{12} - 4096\cdot c^{10} + 2592\cdot c^{8} - 1008\cdot c^{6} + 5944\cdot c^{4} - 1830\cdot c^{2} + 147}{512\cdot s^{10}\cdot(6\cdot c^{2}-1)} =$$ 8.9186 -

C3 $$C_{3} = -\frac{1}{4\cdot c\cdot s} =$$ -0.1129 -

C4 $$C_{4} = \frac{12\cdot c^{8} + 36\cdot c^{6} - 162\cdot c^{4} + 141\cdot c^{2} - 27}{192\cdot c\cdot s^{9}} =$$ 0.1420 -

K1 $$K_{1} = \lambda\cdot A_{11} + \lambda^{3}\cdot A_{13} + \lambda^{5}\cdot A_{15} =$$ 0.1553 -

K2	$K_2 = \lambda^2 \cdot A_{22} + \lambda^4 \cdot A_{24} =$	0.0065	-
K3	$K_3 = \lambda^3 \cdot A_{33} + \lambda^5 \cdot A_{35} =$	0.0001	-
K4	$K_4 = \lambda^4 \cdot A_{44} =$	0.0000	-
K5	$K_5 = \lambda^5 \cdot A_{55} =$	0.0000	-

Project	**: N05-A Pipeline Design**
Project #	: 19018
Subject	: Static & Dynamic Span Analysis
File #	: 19018-60-CAL-01004-01-01 - Allowable free span (static & dynamic) calculations - 26m.xlsm
Client	: ONE-Dyas
Client File #	:

Originator	: EvW	Checked	: PF
Date	: 24/01/2020		
Revision	: 01		

Horizontal wave particle velocities

Water depth at which data required, z (w.r.t. seabed) 0.5080 m

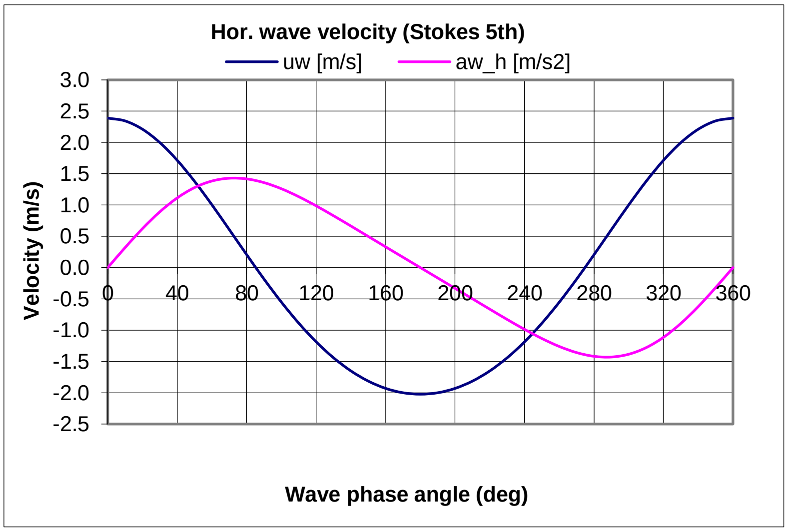
Horizontal velocity, u_w

$$u_w = \frac{L}{T} \cdot \sum_{n=1}^{5} n \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \cos(n \cdot \varphi)$$

Horizontal acceleration, $a_{w,h}$

$$a_{w,h} = \frac{2 \cdot \pi \cdot L}{T^2} \cdot \sum_{n=1}^{5} n^2 \cdot K_n \cdot \cosh\left(n \cdot \frac{2 \cdot \pi}{L} \cdot z\right) \cdot \sin(n \cdot \varphi)$$

ϕ [deg.]	uw [m/s]	aw_h [m/s^2]
0.00	2.3895	0.0000
10.00	2.3444	0.3205
20.00	2.2113	0.6233
30.00	1.9978	0.8921
40.00	1.7152	1.1138
50.00	1.3781	1.2793
60.00	1.0030	1.3842
70.00	0.6070	1.4288
80.00	0.2065	1.4177
90.00	-0.1839	1.3583
100.00	-0.5520	1.2602
110.00	-0.8883	1.1334
120.00	-1.1862	0.9871
130.00	-1.4411	0.8289
140.00	-1.6507	0.6647
150.00	-1.8139	0.4983
160.00	-1.9303	0.3317
170.00	-2.0000	0.1656
180.00	-2.0233	0.0000
190.00	-2.0000	-0.1656
200.00	-1.9303	-0.3317



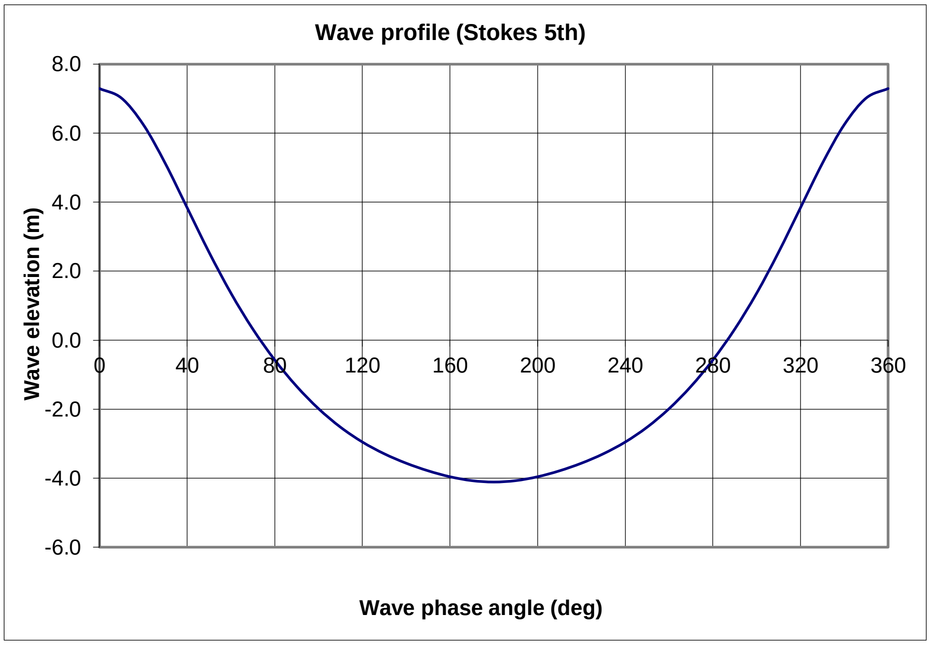
210.00	-1.8139	-0.4983
220.00	-1.6507	-0.6647
230.00	-1.4411	-0.8289
240.00	-1.1862	-0.9871
250.00	-0.8883	-1.1334
260.00	-0.5520	-1.2602
270.00	-0.1839	-1.3583
280.00	0.2065	-1.4177
290.00	0.6070	-1.4288
300.00	1.0030	-1.3842
310.00	1.3781	-1.2793
320.00	1.7152	-1.1138
330.00	1.9978	-0.8921
340.00	2.2113	-0.6233
350.00	2.3444	-0.3205
360.00	2.3895	0.0000

U_{wm} = max. wave particle velocity = 2.39 m/s

Wave profile h(t)

$$\eta(t)=\frac{L}{2\cdot\pi}\left\{\lambda\cdot\cos(\varphi)+\left(\lambda^2\cdot B_{22}+\lambda^4\cdot B_{24}\right)\cdot\cos(2\varphi)+\left(\lambda^3\cdot B_{33}+\lambda^5\cdot B_{35}\right)\cdot\cos(3\varphi)+\lambda^4\cdot B_{44}\cdot\cos(4\varphi)+\lambda^5\cdot B_{55}\cdot\cos(5\varphi)\right\}$$

ϕ (deg.)	η(t) (m)
0.00	7.2930
10.00	7.0176
20.00	6.2468
30.00	5.1259
40.00	3.8385
50.00	2.5483
60.00	1.3614
70.00	0.3208
80.00	-0.5742
90.00	-1.3393
100.00	-1.9865
110.00	-2.5217
120.00	-2.9522
130.00	-3.2934
140.00	-3.5660
150.00	-3.7866
160.00	-3.9586
170.00	-4.0716
180.00	-4.1115
190.00	-4.0716
200.00	-3.9586
210.00	-3.7866
220.00	-3.5660
230.00	-3.2934
240.00	-2.9522
250.00	-2.5217
260.00	-1.9865
270.00	-1.3393
280.00	-0.5742
290.00	0.3208
300.00	1.3614
310.00	2.5483
320.00	3.8385
330.00	5.1259
340.00	6.2468
350.00	7.0176
360.00	7.2930



Static & Dynamic Span - 20" x 20.62 mm

Condition Overview

	Pressure (barg)	Temp. (deg. C)	Content (kg/m3)
Installation (P_{in}, T_{in})	2	15	1025
Hydrotest (P_t, T_t)	144	15	1025
Design (P_d, T_d)	111	50	88.7

Pipeline properties

Nominal diameter		OD_{nom} =	20"	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Internal diameter	$ID = OD_{nom} - 2 \cdot d_{nom}$	ID =	466.76	mm
Cross sectional area of steel	$A_s = \frac{\pi}{4} \cdot \{OD_{nom}^2 - ID^2\}$	A_s =	31572	mm^2
Section modulus	$W_s = \frac{\pi}{32} \cdot \frac{\{OD_{nom}^4 - ID^4\}}{OD_{nom}}$	W_s =	3697384	mm^3
Moment of Inertia	$I_s = \frac{\pi}{64} \cdot \{OD_{nom}^4 - ID^4\}$	I_s =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm

Piggyback

Nominal diameter	$OD_{nom,p}$ =	0	mm
Nominal wall thickness	$d_{nom,p}$ =	0.0	mm

Coating and insulation data

Thickness line pipe	=	3	mm
Thickness piggyback	=	0	mm
Density	=	930	kg/m^3

Constants

gravitational acceleration	g =	9.81	m/s^2

Material

	=	L360NB	
Design temperature	T_d =	50	°C
Yield at ambient/hydrotest temperature	R_e =	360.00	N/mm^2
Yield at design temperature	R_{ed} =	360.00	N/mm^2
Density	ρ_{st} =	7850	kg/m3
Youngs modulus	E_s =	210000	N/mm^2
Poisson's ratio	u =	0.3	-
Linear thermal expansion coefficient	a =	1.16E-05	m/m/°C

Weights

		installation (N/m)	hydrotest (N/m)	operation (N/m)
air	line pipe	2431.3	2431.3	2431.3
	content	1720.6	1720.6	148.9
	coating	43.9	43.9	43.9
	piggyback	0.0	0.0	0.0
	coating pb	0.0	0.0	0.0
buoyancy	line pipe	2086.5	2086.5	2086.5
	piggyback	0.0	0.0	0.0

$$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$$

$$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$$

Static & Dynamic span to be checked for the following environmental load combinations

Condition	Wave velocity	Current velocity	Comment
Installation	$H_{max,1yr}$	1 yr	
Hydrotest	$H_{max,1yr}$	1 yr	
Operational	$H_{max,100yr}$	10 yr	LC1
	$H_{max,10yr}$	100 yr	LC2

Project	**: N05-A Pipeline Design**
Project #	: 19018
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File #	: 19018-60-CAL-01004-02-01 - Allowable free span (static & dynamic) calculations - 8m.xlsm
Client	: ONE-Dyas
Client File #	: 19018-60-CAL-01004-02-01 - Allowable free span (static & dynamic) calculations - 8m.xlsm

Originator	: EvW	Checked	: PF
Date	: 27/01/2020		
Revision	: 01		

Environmental conditions

Water depths:

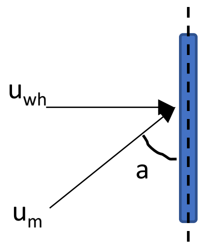
Seawater density		ρ_{sw} =	1025	kg/m³
Maximum water depth		WD_{max} =	11.5	m LAT
Minimum water depth		WD_{min} =	8	m LAT
Other water depth (user input)		WD =	8	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.14	m LAT
Storm surge, RP10 yr		ss_{10yr} =	-0.46	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-0.78	m LAT
Storm surge water level, RP1 yr	$SSWL_{1yr} = WD + ss_{1yr}$	$SSWL_{1yr}$ =	7.86	m LAT
Storm surge water level, RP10 yr	$SSWL_{10yr} = WD + ss_{10yr}$	$SSWL_{10yr}$ =	7.54	m LAT
Storm surge water level, RP100 yr	$SSWL_{100yr} = WD + ss_{100yr}$	$SSWL_{100yr}$ =	7.22	m LAT
Highest Astronomical Tide		HAT =	3.5	m

Waves (H_{max} & T_{max}):

Maximum wave height, RP1 yr - installation/hydrotest	$H_{max,1}$ =	5.2	m
Associated maximum wave period, RP1 yr	$T_{ass,1}$ =	7.7	s
Maximum wave height, RP10 yr - operational	$H_{max,10}$ =	5.7	m
Associated maximum wave period, RP10 yr	$T_{ass,10}$ =	7.9	s
Maximum wave height, RP100 yr - operational	$H_{max,100}$ =	6.2	m
Associated maximum wave period, RP100 yr	$T_{ass,100}$ =	8.1	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0089	0.0093	0.0096
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0135	0.0123	0.0112
theory	Wave particle velocity directly from metocean data		
maximum wave particle velocity (u_{wm})	1.30	1.50	1.60
angle of attack relative to P/L axis (a)	90	90	90
horizontal wave velocity ⊥ to P/L (u_{wh})	1.30	1.50	1.60



Current:

Height above seabed at which velocity is known	z* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.89	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	1	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.12	m/s

Current velocity at reference height: $U_{czr} = u_{st} + u_{ss}$

$U_{czr,1}$ =	0.89	m/s
$U_{czr,10}$ =	1	m/s
$U_{czr,100}$ =	1.12	m/s

Angle of attack relative to pipeline axis α_{uc} = 90 deg

Horizontal current velocity ⊥ to P/L:

$$u_{cm,perp} = \frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc})$$

$u_{cm,perp,1}$ =	0.707	m/s
$u_{cm,perp,10}$ =	0.794	m/s
$u_{cm,perp,100}$ =	0.890	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Hydrodunamic forces:

Maximum absolute hydrodynamic force (F_D+F_I), RP1 yr (installation/hydrotest condition)	891	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP100/10 yr (LC 1 operational condition)	1269	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP10/100 yr (LC 2operational condition)	1264	N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Table 3 - NEN 3656 load factors

Load factor	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
Self weight & content	1.1	1.1	1.1	1.1	
Coating	1.2	1.2	1.2	1.2	
Marine growth	0	0	1.2	1.2	
Internal pressure	0	1.15	1.15	1.15	
external pressure	1.1	1.1	1.1	1.1	
temperature	1	1.1	1.1	1.1	
environmental load	1.1	1.2	1.2	1.2	
Pipe bundle weight in air	4619.8	4619.8	2891.0	2891.0	N/m; incl. load factors
Submerged bundle weight, Ws	2324.7	2324.7	595.9	595.9	N/m; incl. load factors
Factored load acting on pipe, q	2523	2559	1635	1629	N/m; $q=\sqrt{\gamma_W{}^2\cdot W_S{}^2+\gamma_H{}^2\cdot(F_D+F_I)^2}$
Pressure	2	144	111	111	barg
DT	11	11	46	46	deg. C
Material factor (table 3; D3.1)	1.1	1.1	1.1	1.1	
Allowable stress (table 3; D3.1)	327.3	556.4	556.4	556.4	N/mm^2

STATIC SPAN LENGTH - INSTALLATION

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression		
Hoop stress	1.3	1.3	1.3	1.3	N/mm^2	$\sigma_H=\frac{(\gamma i\cdot Pi-\gamma e\cdot Pe)\cdot(OD-d_{min})}{2\cdot d_{min}}$
Max. long. Stress	327.9	-326.6	327.9	-326.6	N/mm^2	$\sigma_{max.long.stress}=\frac{\sigma_H\pm\sqrt{-3\cdot\sigma_H^2+4\cdot\sigma_{allow}^2}}{2}$
Long. hoop stress	0.7	0.7	0.4	0.4	N/mm^2	$\sigma_{long.hoop.stress}=v\cdot\sigma_H$
Thermal exp. stress	n/a	n/a	-26.8	-26.8	N/mm^2	$\sigma_{thermal}=-\gamma_t\cdot\alpha\cdot E_s\cdot\Delta T$
Max. allow. bending stress	327.3	327.3	327.3	-300.2	N/mm^2	$\sigma_{b,max}=\sigma_{max.long.stress}-\sigma_{lonh.hoop.stress}-\sigma_{thermal}$
Maximum span	69.3	69.3	69.3	66.3	m	

STATIC SPAN LENGTH - HYDROTEST

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression	
Hoop stress	251.2	251.2	251.2	251.2	N/mm^2
Max. long. Stress	637.7	-386.4	637.7	-386.4	N/mm^2
Long. hoop stress	85.8	85.8	75.4	75.4	N/mm^2
Thermal exp. stress	n/a	n/a	-29.5	-29.5	N/mm^2
Max. allow. bending stress	551.8	-472.3	556.4	-432.3	N/mm^2
Maximum span	89.3	82.6	89.7	79.0	m

STATIC SPAN LENGTH - OPERATION LC1

	Unrestrained pipe tension	Unrestrained pipe compression	Restrained pipe tension	Restrained pipe compression	
Hoop stress	193.3	193.3	193.3	193.3	N/mm^2
Max. long. Stress	627.2	-433.9	627.2	-433.9	N/mm^2
Long. hoop stress	66.2	66.2	58.0	58.0	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-500.1	556.4	-368.6	N/mm^2
Maximum span	112.2	106.4	112.2	91.3	m

STATIC SPAN LENGTH - OPERATION LC2

	Unrestrained pipe		Restrained pipe		
	tension	compression	tension	compression	
Hoop stress	193.3	193.3	193.3	193.3	N/mm^2
Max. long. Stress	627.2	-433.9	627.2	-433.9	N/mm^2
Long. hoop stress	66.2	66.2	58.0	58.0	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-500.1	556.4	-368.6	N/mm^2
Maximum span	112.4	106.5	112.4	91.5	m

Project	**: N05-A Pipeline Design**	
Project #	: 19018	
Subject	: Static & Dynamic Span Analysis	
File #	: 19018-60-CAL-01004-02-01 - Allowable free span (static & dynamic) calculations - 8m.xlsm	
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Client File #	: 19018-60-CAL-01004-02-01 - Allowable free span (static & dynamic) calculations - 8m.xlsm	

Originator	: EvW	Checked	: PF
Date	: 27/01/2020		
Revision	: 01		

DYNAMIC SPAN ANALYSIS (NEN 3656 - I.5.2.5)

Assessment Stability parameter, Ks < 1.8 => in-line vibration
Stability parameter, Ks < 16 => cross flow vibration

$$K_s = \frac{2m \text{ x } \delta}{\rho_w \text{ x } D_o^2}$$

Where,

d = damping factor water: 0.02 x 2 x π	=	0.126	-
r_w = seawater density	=	1025	kg/m³
D_o = outer diameter (incl. coating)	=	514	mm
m = effective mass			
m = W_{bundle} + M_{added}			
$M_{added} = \frac{\pi}{4} \cdot C_m \cdot \rho_w \cdot D_{o,eq}^2$			
C_m = added mass coefficient	=	1.2	-
$D_{o,eq}$ = equivalent diameter (incl. coating)	=	514	mm

Due to the presense of 2 objects attached to eachother, velocity flow intensification occurs:

$v_{tot} = (v_{wave} + v_{cur}) \text{ x } (1 + f_{int})$; $\quad f_{int} = \left\{1 + \left(\frac{D_{ob}^2}{4 \cdot CL^2}\right)\right\}$

Where,
D_{ob} = diameter of obstruction
CL = centerline distance P/L - obstruction

IN-LINE VIV:

Given the stability factor (Ks), the horizontal particle velocity (v), possibly including vicinity factor and the reduced velocity (Vr), the first eigen frequency (f1) can be determined prior to vibration occurring.

Reduced velocity, Vr, based on NEN 3656 I.5.2.5.2

$$V_r = \frac{v}{f_1 \times D_o}$$

if $1{,}0 \leq V_r \leq 3{,}5$ then oscillation occurs => Vr<1,0 design criterium

Vr is set to 1 as conservative value; Vr = 1.0 -

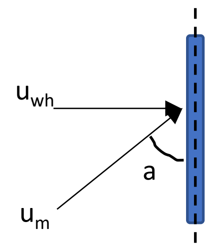
$$f_1 = \frac{a}{2\pi}\sqrt{\frac{E \times I}{m \times L^4}}$$

Where,
a = frequency factor (22 for fixed/fixed; 9.87 for pinned/pinned)
a = 15.4 for fixed/pinned a = 15.4 -

Waves (Hs & Tz):

Significant wave height, RP1 yr - installation/hydrotest	$H_{s,1}$ =	3.9	m
Associated wave period, RP1 yr	$T_{z,1}$ =	6.4	s
Significant wave height, RP10 yr - operational	$H_{s,10}$ =	4.1	m
Associated wave period, RP10 yr	$T_{z,10}$ =	6.5	s
Significant wave height, RP100 yr - operational	$H_{s,100}$ =	4.2	m
Associated wave period, RP100 yr	$T_{z,100}$ =	6.6	s

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0097	0.0099	0.0098
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0196	0.0182	0.0169
theory	Wave particle velocity directly from metocean data		
maximum wave particle velocity (u_{wm})	1.30	1.50	1.60
angle of attack relative to P/L axis (a)	90	90	90
horizontal wave velocity ⊥ to P/L (u_{wh})	1.30	1.50	1.60



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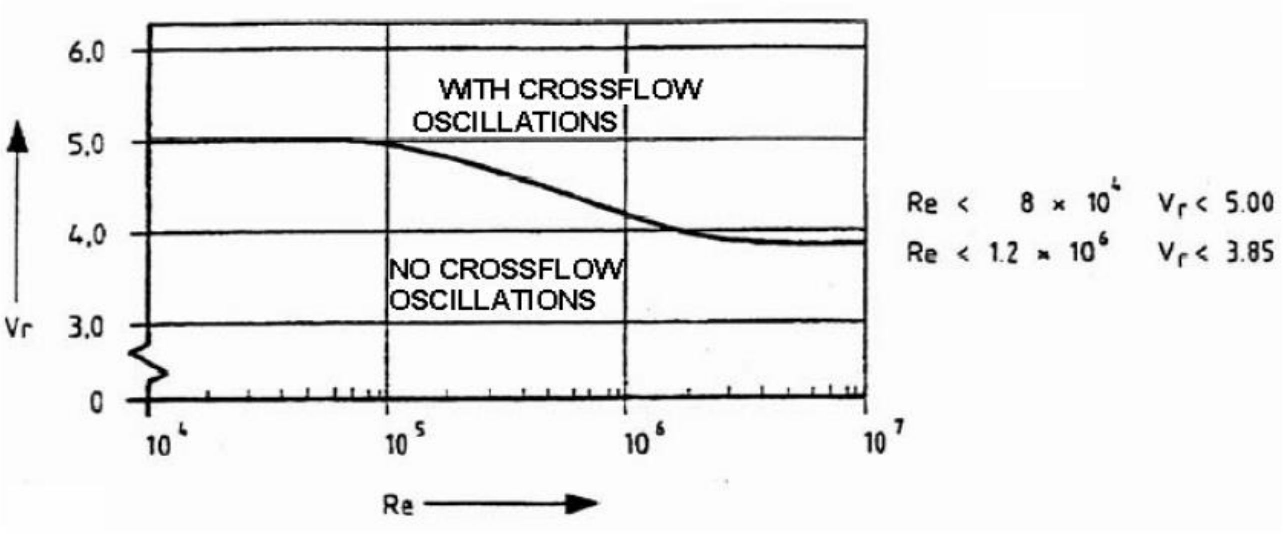
Originator	: EvW		Checked	: PF
Date	: 27/01/2020			
Revision	: 01			

	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
effective mass	682.9	682.9	522.7	522.7	kg/m
K_s	0.63	0.63	0.49	0.49	-
In-line VIV	yes	yes	yes	yes	-
cross flow VIV	yes	yes	yes	yes	-
Vr	1.00	1.00	1.00	1.00	-
u_{wh}	0.71	0.71	0.79	0.89	m/s, set equal to Ucm, for velocity ratio 0.5
$u_{cm,perp}$	0.71	0.71	0.79	0.89	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp}) \times (1+0.5 \cdot f_{int}) = v_{tot}$	1.41	1.41	1.59	1.78	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
f1	2.75	2.75	3.09	3.46	1/s
$L_{span,in}$	21.9	21.9	22.1	20.9	m

note: f_{int} is taken into account for 50% as system doesn't instantaneously respond and vortices occur in a relatively steady state environment, which this isn't.

CROSS FLOW VIV:
Oscillation area for cross flow is given by the figure below and depends on the Reynolds number (R_e) $R_e = \frac{v \cdot D_o}{\nu_d}$

v = horizontal particle velocity (v_{tot})
D_o = outer diameter (incl. coating) = 514 mm
u_d = dynamic viscosity seawater u_d = 4.99E-07 m^2/s
Vr is set to 3.85 as conservative value; Vr = 3.85 -



	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
u_{wh}	1.30	1.30	1.60	1.50	m/s
$u_{cm,perp}$	0.71	0.71	0.79	0.89	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp}) \times (1+0.5 \cdot f_{int}) = v_{tot}$	2.01	2.01	2.39	2.39	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
Reynolds nr.	2.07E+06	2.07E+06	2.47E+06	2.46E+06	-
Vr	3.850	3.850	3.850	3.850	-
f1	1.01	1.01	1.21	1.21	1/s
$L_{span,cross}$	36.0	36.0	35.3	35.3	m

SUMMARY - SPAN ANALYSIS

	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
$L_{span,in}$	21.9	21.9	22.1	20.9	m
$L_{span,cross}$	36.0	36.0	35.3	35.3	m

Maximum Span Length = 20.9 m

Project	: **N05-A Pipeline Design**		
Project #	: 19018		
Subject	: Static & Dynamic Span Analysis		
File #	: 19018-60-CAL-01004-03-02 - Allowable free span (static & dynamic) calculations - 17m.xlsm		
Client	: ONE-Dyas		
Client File #	: 19018-60-CAL-01004-03-02 - Allowable free span (static & dynamic) calculations - 17m.xlsm		

enersea

Originator	: EvW	Checked	: PF
Date	: 12-3-2020		
Revision	: 02		

Static & Dynamic Span - 20" x 20.62 mm

Condition Overview

	Pressure (barg)	Temp. (deg. C)	Content (kg/m3)
Installation (P_{in}, T_{in})	2	15	1025
Hydrotest (P_t, T_t)	144	15	1025
Design (P_d, T_d)	111	50	88.7

Pipeline properties				
Nominal diameter		OD_{nom} =	20"	
Nominal diameter		OD_{nom} =	508	mm
Nominal wall thickness		d_{nom} =	20.62	mm
Internal diameter	$ID = OD_{nom} - 2 \cdot d_{nom}$	ID =	466.76	mm
Cross sectional area of steel	$A_s = \frac{\pi}{4} \cdot \{OD_{nom}^2 - ID^2\}$	A_s =	31572	mm^2
Section modulus	$W_s = \frac{\pi}{32} \cdot \frac{\{OD_{nom}^4 - ID^4\}}{OD_{nom}}$	W_s =	3697384	mm^3
Moment of Inertia	$I_s = \frac{\pi}{64} \cdot \{OD_{nom}^4 - ID^4\}$	I_s =	939135656	mm^4
Corrosion allowance		CA =	3	mm
Fabrication Tolerance		f_{tol} =	7.25	%
Minimum wall thickness	$d_{min} = d_{nom} \cdot \{1 - f_{tol}\} - CA$	d_{min} =	16.1	mm
Average pipe diameter	$OD_g = 1/2 \cdot \{OD_{nom} + (OD_{nom} - 2 \cdot t_{min})\}$	OD_g =	491.9	mm
Piggyback				
Nominal diameter		$OD_{nom,p}$ =	0	mm
Nominal wall thickness		$d_{nom,p}$ =	0.0	mm
Coating and insulation data				
Thickness line pipe		=	3	mm
Thickness piggyback		=	0	mm
Density		=	930	kg/m^3
Constants				
gravitational acceleration		g =	9.81	m/s^2
Material		=	L360NB	
Design temperature		T_d =	50	°C
Yield at ambient/hydrotest temperature		R_e =	360.00	N/mm^2
Yield at design temperature		R_{ed} =	360.00	N/mm^2
Density		ρ_{st} =	7850	kg/m3
Youngs modulus		E_s =	210000	N/mm^2
Poisson's ratio		υ =	0.3	-
Linear thermal expansion coefficient		α =	1.16E-05	m/m/°C

Weights

		installation (N/m)	hydrotest (N/m)	operation (N/m)
air	line pipe	2431.3	2431.3	2431.3
	content	1720.6	1720.6	148.9
	coating	43.9	43.9	43.9
	piggyback	0.0	0.0	0.0
	coating pb	0.0	0.0	0.0
buoyancy	line pipe	2086.5	2086.5	2086.5
	piggyback	0.0	0.0	0.0

$$W_{pipe} = \{A_s \cdot \rho_s + A_{coat} \cdot \rho_{coat} + A_{inside} \cdot \rho_{content}\} \cdot g$$

$$F_b = \frac{\pi}{4} \cdot OD_{tot}^2 \cdot \rho_{seawater} \cdot g$$

Static & Dynamic span to be checked for the following environmental load combinations

Condition	Wave velocity	Current velocity	Comment
Installation	$H_{max,1yr}$	1 yr	
Hydrotest	$H_{max,1yr}$	1 yr	
Operational	$H_{max,100yr}$	10 yr	LC1
	$H_{max,10yr}$	100 yr	LC2

Environmental conditions

Water depths:

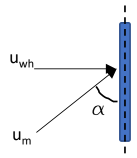
Seawater density		ρ_{sw} =	1025	kg/m³
Maximum water depth		WD_{max} =	20.59	m LAT
Minimum water depth		WD_{min} =	17	m LAT
Other water depth (user input)		WD =	17	m LAT
Storm surge, RP1 yr		ss_{1yr} =	-0.58	m LAT
Storm surge, RP10 yr		ss_{10yr} =	-0.93	m LAT
Storm surge, RP100 yr		ss_{100yr} =	-1.285	m LAT
Storm surge water level, RP1 yr	$SSWL_{1yr} = WD + ss_{1yr}$	$SSWL_{1yr}$ =	16.42	m LAT
Storm surge water level, RP10 yr	$SSWL_{10yr} = WD + ss_{10yr}$	$SSWL_{10yr}$ =	16.07	m LAT
Storm surge water level, RP100 yr	$SSWL_{100yr} = WD + ss_{100yr}$	$SSWL_{100yr}$ =	15.715	m LAT
Highest Astronomical Tide		HAT =	3.11	m

Waves (H_{max} & T_{max}):

Maximum wave height, RP1 yr - installation/hydrotest	$H_{max,1}$ =	8.3	m
Associated maximum wave period, RP1 yr	$T_{ass,1}$ =	8.9	s
Maximum wave height, RP10 yr - operational	$H_{max,10}$ =	10.1	m
Associated maximum wave period, RP10 yr	$T_{ass,10}$ =	9.4	s
Maximum wave height, RP100 yr - operational	$H_{max,100}$ =	11.55	m
Associated maximum wave period, RP100 yr	$T_{ass,100}$ =	9.8	s

Applied wave theory (per fig. 6.36 "Dynamics of Fixed Marine Structures")

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0107	0.0117	0.0123
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0211	0.0185	0.0167
theory	interpolation between data of 8 and 26m water depth		
maximum wave particle velocity (u_{wm})	1.85	2.38	2.80
angle of attack relative to P/L axis (α)	90	90	90
horizontal wave velocity ⊥ to P/L (u_{wh})	1.85	2.38	2.80



Current:

Height above seabed at which velocity is known	z* =	1	m
Spring tide	u_{st} =	0	m/s
Storm surge, RP1 yr	$u_{ss,1}$ =	0.82	m/s
Storm surge, RP10 yr	$u_{ss,10}$ =	0.92	m/s
Storm surge, RP100 yr	$u_{ss,100}$ =	1.04	m/s

Current velocity at reference height: $U_{czr} = u_{st} + u_{ss}$

$U_{czr,1}$ =	0.82	m/s
$U_{czr,10}$ =	0.92	m/s
$U_{czr,100}$ =	1.04	m/s

Angle of attack relative to pipeline axis α_{uc} = 90 deg

Horizontal current velocity ⊥ to P/L:

$$u_{cm,perp} = \frac{7}{8} \cdot U_{czr} \cdot \left(\frac{OD_{nom}}{z_r}\right)^{1/7} \cdot \sin(\alpha_{uc})$$

$u_{cm,perp,1}$ =	0.647	m/s
$u_{cm,perp,10}$ =	0.731	m/s
$u_{cm,perp,100}$ =	0.826	m/s

Hydrodynamic coefficients:

Drag coefficient	C_D =	0.7	-
Lift coefficient	C_L =	0.9	-
Inertia coefficient	C_I =	3.29	-

Hydrodunamic forces:

Maximum absolute hydrodynamic force (F_D+F_I), RP1 yr (installation/hydrotest condition)	1392	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP100/10 yr (LC 1 operational condition)	2976	N/m
Maximum absolute hydrodynamic force (F_D+F_I), RP10/100 yr (LC 2operational condition)	2360	N/m

Temperatures:

Ambient temperature T_{amb} = 4 deg. C

Project	**:**	**N05-A Pipeline Design**
Project #	**:**	19018
Subject	**:**	Static & Dynamic Span Analysis
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Client	**:**	ONE-Dyas
Client File #	**:**	19018-60-CAL-01004-03-02 - Allowable free span (static & dynamic) calculations - 17m.xlsm

Originator	: EvW		Checked	: PF
Date	: 12-3-2020			
Revision	: 02			

Table 3 - NEN 3656 load factors

Load factor	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
Self weight & content	1.1	1.1	1.1	1.1	
Coating	1.2	1.2	1.2	1.2	
Marine growth	0	0	1.2	1.2	
Internal pressure	0	1.15	1.15	1.15	
external pressure	1.1	1.1	1.1	1.1	
temperature	1	1.1	1.1	1.1	
environmental load	1.1	1.2	1.2	1.2	
Pipe bundle weight in air	4619.8	4619.8	2891.0	2891.0	N/m; incl. load factors
Submerged bundle weight, Ws	2324.7	2324.7	595.9	595.9	N/m; incl. load factors
Factored load acting on pipe, q	2784	2863	3621	2894	N/m; $q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$
Pressure	2	144	111	111	barg
ΔT	11	11	46	46	deg. C
Material factor (table 3; D3.1)	1.1	1.1	1.1	1.1	
Allowable stress (table 3; D3.1)	327.3	556.4	556.4	556.4	N/mm^2

STATIC SPAN LENGTH - INSTALLATION

	Unrestrained pipe		Restrained pipe			
	tension	compression	tension	compression		
Hoop stress	2.9	2.9	2.9	2.9	N/mm^2	$\sigma_H = \frac{(\gamma i \cdot Pi - \gamma e \cdot Pe) \cdot (OD - d_{min})}{2 \cdot d_{min}}$
Max. long. Stress	328.7	-325.8	328.7	-325.8	N/mm^2	$\sigma_{max.long.stress} = \frac{\sigma_H \pm \sqrt{-3 \cdot \sigma_H^2 + 4 \cdot \sigma_{allow}^2}}{2}$
Long. hoop stress	1.2	1.2	0.9	0.9	N/mm^2	$\sigma_{long.hoop.stress} = \nu \cdot \sigma_H$
Thermal exp. stress	n/a	n/a	-26.8	-26.8	N/mm^2	$\sigma_{thermal} = -\gamma_t \cdot \alpha \cdot E_s \cdot \Delta T$
Max. allow. bending stress	327.3	-327.1	327.3	-299.9	N/mm^2	$\sigma_{b,max} = \sigma_{max.long.stress} - \sigma_{lonh.hoop.stress} - \sigma_{thermal}$
Maximum span	65.9	65.9	65.9	63.1	m	

STATIC SPAN LENGTH - HYDROTEST

	Unrestrained pipe		Restrained pipe		
	tension	compression	tension	compression	
Hoop stress	249.7	249.7	249.7	249.7	N/mm^2
Max. long. Stress	637.5	-387.8	637.5	-387.8	N/mm^2
Long. hoop stress	85.8	85.8	74.9	74.9	N/mm^2
Thermal exp. stress	n/a	n/a	-29.5	-29.5	N/mm^2
Max. allow. bending stress	551.6	-473.6	556.4	-433.2	N/mm^2
Maximum span	84.4	78.2	84.8	74.8	m

STATIC SPAN LENGTH - OPERATION LC1

	Unrestrained pipe		Restrained pipe		
	tension	compression	tension	compression	
Hoop stress	191.8	191.8	191.8	191.8	N/mm^2
Max. long. Stress	626.9	-435.1	626.9	-435.1	N/mm^2
Long. hoop stress	66.2	66.2	57.6	57.6	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-501.2	556.4	-369.4	N/mm^2
Maximum span	75.4	71.5	75.4	61.4	m

STATIC SPAN LENGTH - OPERATION LC2

	Unrestrained pipe		Restrained pipe		
	tension	compression	tension	compression	
Hoop stress	191.8	191.8	191.8	191.8	N/mm^2
Max. long. Stress	626.9	-435.1	626.9	-435.1	N/mm^2
Long. hoop stress	66.2	66.2	57.6	57.6	N/mm^2
Thermal exp. stress	n/a	n/a	-123.3	-123.3	N/mm^2
Max. allow. bending stress	556.4	-501.2	556.4	-369.4	N/mm^2
Maximum span	84.3	80.0	84.3	68.7	m

DYNAMIC SPAN ANALYSIS (NEN 3656 - I.5.2.5)

Assessment Stability parameter, Ks < 1.8 => in-line vibration
Stability parameter, Ks < 16 => cross flow vibration

$$K_s = \frac{2m \text{ x } \delta}{\rho_w \text{ x } D_o^2}$$

Where,

δ = damping factor water: 0.02 x 2 x π	=	0.126	-
ρ_w = seawater density	=	1025	kg/m³
D_o = outer diameter (incl. coating)	=	514	mm

m = effective mass

$$m = W_{bundle} + M_{added}$$

$$M_{added} = \frac{\pi}{4} \cdot C_m \cdot \rho_w \cdot D_{o,eq}^2$$

C_m = added mass coefficient	=	1.2	-
$D_{o,eq}$ = equivalent diameter (incl. coating)	=	514	mm

Due to the presense of 2 objects attached to eachother, velocity flow intensification occurs:

$v_{tot} = (v_{wave} + v_{cur}) \text{ x } (1 + f_{int})$; $\quad f_{int} = \left\{1 + \left(\frac{D_{ob}^2}{4 \cdot CL^2}\right)\right\}$

Where,
D_{ob} = diameter of obstruction
CL = centerline distance P/L - obstruction

IN-LINE VIV:

Given the stability factor (Ks), the horizontal particle velocity (v), possibly including vicinity factor and the reduced velocity (Vr), the first eigen frequency (f1) can be determined prior to vibration occurring.

Reduced velocity, Vr, based on NEN 3656 I.5.2.5.2

$$V_r = \frac{v}{f_1 \times D_o} \quad \text{if} \quad 1{,}0 \le V_r \le 3{,}5$$

then oscillation occurs => Vr<1,0 design criterium

Vr is set to 1 as conservative value; Vr = 1.0 -

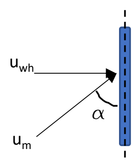
$$f_1 = \frac{a}{2\pi}\sqrt{\frac{E \times I}{m \times L^4}}$$

Where,
a = frequency factor (22 for fixed/fixed; 9.87 for pinned/pinned)
a = 15.4 for fixed/pinned a = 15.4 -

Waves (Hs & Tz):

Significant wave height, RP1 yr - installation/hydrotest	$H_{s,1}$ =	5.2	m
Associated wave period, RP1 yr	$T_{z,1}$ =	8.2	s
Significant wave height, RP10 yr - operational	$H_{s,10}$ =	6.25	m
Associated wave period, RP10 yr	$T_{z,10}$ =	8.9	s
Significant wave height, RP100 yr - operational	$H_{s,100}$ =	7.05	m
Associated wave period, RP100 yr	$T_{z,100}$ =	9.45	s

	1 yr	10 yr	100 yr
$\frac{H}{g \cdot T_{ass}^2}$	0.0080	0.0080	0.0080
$\frac{SWL}{g \cdot T_{ass}^2}$	0.0252	0.0207	0.0179
theory	interpolation between data of 8 and 26m water depth		
maximum wave particle velocity (u_{wm})	1.33	1.76	2.08
angle of attack relative to P/L axis (α)	90	90	90
horizontal wave velocity⊥ to P/L (u_{wh})	1.33	1.76	2.08



Project : **N05-A Pipeline Design**
Project # : 19018
Subject : Static & Dynamic Span Analysis
File # : 19018-60-CAL-01004-03-02 - Allowable free span (static & dynamic) calculations - 17m.xlsm

Client : ONE-Dyas
Client File # : 19018-60-CAL-01004-03-02 - Allowable free span (static & dynamic) calculations - 17m.xlsm

Originator : EvW — Checked : PF
Date : 12-3-2020
Revision : 02

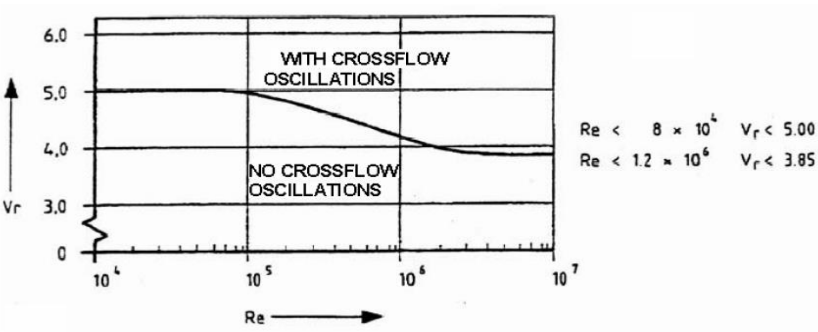
	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
effective mass	682.9	682.9	522.7	522.7	kg/m
K_s	0.63	0.63	0.49	0.49	-
In-line VIV	yes	yes	yes	yes	-
cross flow VIV	yes	yes	yes	yes	-
Vr	1.00	1.00	1.00	1.00	-
u_{wh}	0.65	0.65	0.73	0.83	m/s, set equal to Ucm, for velocity ratio 0.5
$u_{cm,perp}$	0.65	0.65	0.73	0.83	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp}) \times (1+0.5 \cdot f_{int}) = v_{tot}$	1.29	1.29	1.46	1.65	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
f1	2.52	2.52	2.84	3.21	1/s
$L_{span,in}$	22.9	22.9	23.0	21.6	m

note: f_{int} is taken into account for 50% as system doesn't instantaneously respond and vortices occur in a relatively steady state environment, which this isn't.

CROSS FLOW VIV:
Oscillation area for cross flow is given by the figure below and depends on the Reynolds number (R_e)

$$R_e = \frac{v \cdot D_o}{v_d}$$

v = horizontal particle velocity (v_{tot})
D_o = outer diameter (incl. coating) = 514 mm
υ_d = dynamic viscosity seawater υ_d = 4.99E-07 m^2/s
Vr is set to 3.85 as conservative value; Vr = 3.85 -



	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
u_{wh}	1.33	1.33	2.08	1.76	m/s
$u_{cm,perp}$	0.65	0.65	0.73	0.83	m/s
D_{ob}	0.0	0.0	0.0	0.0	mm
CL	294.0	294.0	294.0	294.0	mm
f_{int}	0.000	0.000	0.000	0.000	-
$(u_{wh} + u_{cm,perp}) \times (1+0.5 \cdot f_{int}) = v_{tot}$	1.97	1.97	2.81	2.58	m/s
D_o	0.5140	0.5140	0.5140	0.5140	m
Reynolds nr.	2.03E+06	2.03E+06	2.90E+06	2.66E+06	-
Vr	3.850	3.850	3.850	3.850	-
f1	1.00	1.00	1.42	1.30	1/s
$L_{span,cross}$	36.4	36.4	32.6	34.0	m

SUMMARY - SPAN ANALYSIS

	Installation	Hydrotest	LC 1 Operation	LC 2 Operation	
$L_{span,in}$	22.9	22.9	23.0	21.6	m
$L_{span,cross}$	36.4	36.4	32.6	34.0	m

Maximum Span Length = 21.6 m

D. Analytical Upheaval Buckling Analysis

The following documents are included:

- 19018-60-CAL-01005-01-01 Upheaval Buckling Analysis – 43 deg

(4 pages)

Client	**:**	ONE-Dyas
Project	**:**	N05A Flowline
Project No.	**:**	19018
Subject	**:**	Pipeline Upheaval Buckling - analytical
Doc. No.	**:**	19018-60-CAL-01005-01
Client Doc. No.	**:**	-

Calc'd by	**:** EvW		**Rev.**	**:**	01
Checked	**:**		**Date**	**:**	24-1-2020

Upheaval buckling calculation

Pipe data

Outside pipe diameter		OD_s =	508	mm
Pipe wall thickness		t_s =	20.62	mm
Internal pipe diameter	$= OD\_s - 2 \cdot t\_s$	ID_s =	466.76	mm

Steel data

Material			L360NB	
Density steel		ρ_s =	7850	kg/m^3
Young's modulus		E_s =	206000	N/mm^2
Poisson's ratio		ν =	0.3	-
Thermal expansion coefficient		α =	1.17E-05	m/m/°C
Steel area	$= \frac{1}{4} \cdot \pi \cdot (OD^2\_s - ID^2\_s)$	A_s =	31572.3	mm^2
Internal pipe area	$= \frac{1}{4} \cdot \pi \cdot ID^2\_s$	A_i =	1.71E+05	mm^2
Moment of inertia	$= \frac{\pi}{64} \cdot (OD^4\_s - ID^4\_s)$	I_s =	9.39E+08	mm^4
Pipe weight in air		W_{pe} =	247.8	kg/m
Sea water density	r_{sw}	=	1025	kg/m^3
Pipeline contents density	r_{cont}	=	88.7	kg/m^3

Internal lining

Thickness		t_l =	0	mm
Density		r_l =	0	kg/m^3
Lining weight		W_l =	0.0	kg/m

Coating data

Outer coating layer 1

Thickness		t_{c1} =	3	mm
Density		ρ_{c1} =	930	kg/m^3
Layer 1 weight	$W_{l1} = \frac{\pi}{4} \cdot \{(OD + 2 \cdot t_{c1})^2 - OD^2\} \cdot \rho_{c1}$	W_{l1} =	4.5	kg/m

Weight piggy back line

Piggy back weight		W_{l2} =	0.0	kg/m

Concrete coating

Thickness		t_{con} =	0	mm
Density		ρ_{con} =	0	kg/m^3
Concrete weight	$W_{con} = \frac{\pi}{4} \cdot \{(OD + 2 \cdot t_{c1} + 2 \cdot t_{c2} + 2 \cdot t_{con})^2 - (OD + 2 \cdot t_{c1} + 2 \cdot t_{c2})^2\} \cdot \rho_{con}$	W_{con} =	0.0	kg/m

Client	: ONE-Dyas
Project	: N05A Flowline
Project No.	: 19018
Subject	: Pipeline Upheaval Buckling - analytical
Doc. No.	: 19018-60-CAL-01005-01
Client Doc. No.	: -

enersea®

Calc'd by	: EvW	**Rev.**	: 01
Checked	:	**Date**	: 24-1-2020

Marine growth

Thickness		t_{mg} =	0	mm
Density		ρ_{mg} =	0	kg/m^3
Marine growth weight	$W_{mg} = \pi/4 \cdot \{(OD+2\cdot t_{c1}+2\cdot t_{c2}+2\cdot t_{con}+2\cdot t_{mg})^2-(OD+2\cdot t_{c1}+2\cdot t_{c2}+2\cdot t_{con})^2\}\cdot \rho_{mg}$	W_{mg} =	0.0	kg/m

Weight data

Total outside diameter	$ODtot = OD+2\cdot t\cdot +2\cdot t_{c2}+2\cdot t_{con}+2\cdot t_{mg}$	OD_{tot} =	514.0	mm
Contents weight	$W_{cont} = \pi/4\cdot(ID-2\cdot t_l)^2\cdot \rho_{cont}$	W_{cont} =	15.2	kg/m
Pipeline weight in air	$w_r = w_{pe}+w_l+w_{l1}+w_{l2}+w_{con}+w_{mg}+w_{cont}$	W_r =	267.5	kg/m
Buoyancy force, F_B	$F_B = \pi/4\cdot OD_{tot}^2\cdot \rho_w$	F_B =	212.7	kg/m
Submerged pipeline weight, W_{sm}	$W_{sm} = W_r - F_B$	W_{sm} =	54.8	kg/m

Soil data

Submerged soil cover density		γ' =	850	kg/m^3
Angle of internal friction		ϕ_{soil} =	28	deg.
Potyondy coeff. Soil		p_{soil} =	0.6	-
Height soil cover from top of pipe		Htop =	0.8	m
Height soil cover from center of pipe		H	1.06	
Soil uplift coefficient		f_{soil} =	0.1	-

(0.5 for dense materials and 0.1 for loose materials)

Soil weight on top of pipe	$q = \gamma'\cdot H\cdot OD_{tot}\cdot(1+f\cdot H/OD_{tot})$	q =	5461.9	N/m
Imperfection height		δ =	600	mm

Pressure data

Design pressure	P_d =	111	barg
Maximum operating pressure	P_i =	95	barg
Minimum external pressure	P_e =	1.01	barg

Temperature data

Seawater temperature, T_{sea}	T_{sea} =	3	^oC
Temperature of gas, T_{gas}	T_{gas} =	43	^oC

Pipeline forces

Compressive temperature force, F_T	$F_T = E\cdot A\cdot \alpha\cdot(T_{gas}-T_{sea})$	F_T =	3043822.4	N
Tensile Poisson force, F_P	$F_P = A_i\cdot \nu\cdot \frac{\{P_D-P_e\}\cdot OD_s}{2\cdot t}$	F_P =	1283345.0	N
Compressive member end force, F_e	$F_e = \{P_D-P_e\}\cdot \pi/4\cdot ID_s^2$	F_e =	1882123.1	N

Is area under considerations within anchor zone (y/n) ? = n

(y: F_T can be neglected)

Effective compressive axial force, F_{eff}	$F_{eff} = F_T - F_P + F_e$	F_{eff} =	3642600.5	N

Required down load

The required download depends on:

- dimensionless maximum download parameter, F_W
- dimensionless imperfection length parameter, F_L

$$\Phi_w = \frac{w \cdot EI}{\delta \cdot F_{eff}^2} \quad \text{and} \quad \Phi_L = L \cdot \sqrt{\frac{F_{eff}}{EI}}$$

where,

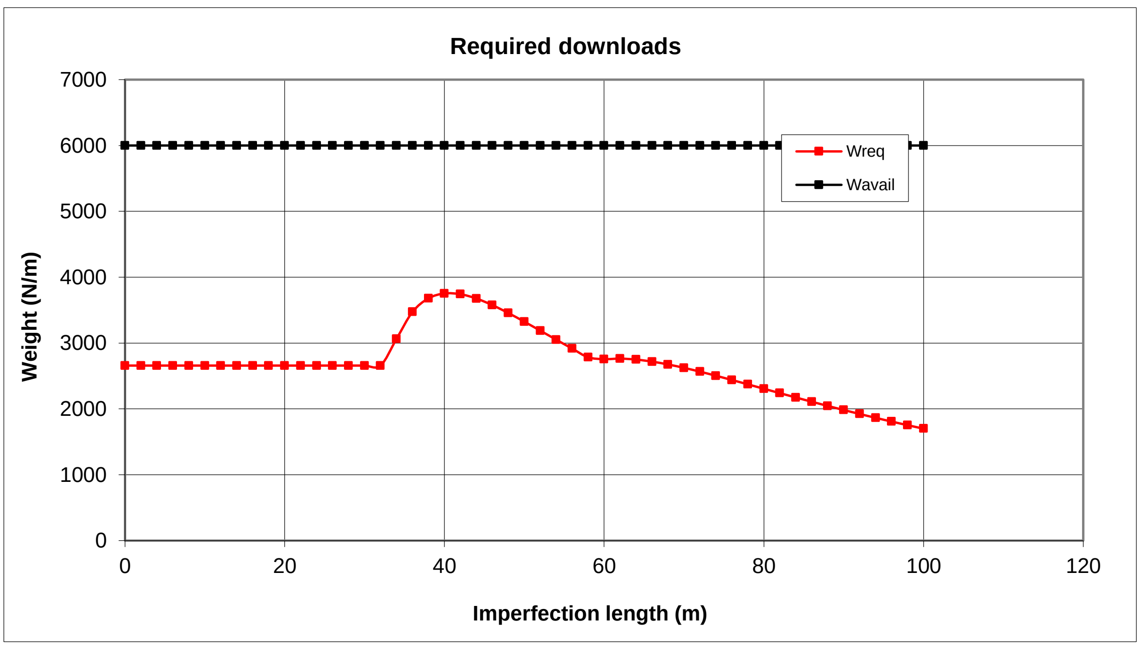
F_W = dimensionless maximum download parameter
w = required download (N/mm)
F_{eff} = effective axial force (N)
EI = bending stiffness pipeline (N/mm^2)
d = imperfection height (mm)
F_L = dimensionless imperferction length parameter
L = imperfection / exposure length (mm)

Requirements:

$$\Phi_L \le 4.49 \qquad \Phi_W = 0.0646$$
$$4.49 < \Phi_L \le 8.06 \qquad \Phi_W = 5.68 / \Phi_L^2 - 88.35 / \Phi_L^4$$
$$\Phi_L > 8.06 \qquad \Phi_W = 9.6 / \Phi_L^2 - 343 / \Phi_L^4$$

L [m]	F_L	F_w	W_{req} [N/m]	W_{avail} [N/m]
0	0.000	0.0646	2658.345	6000
2	0.274	0.0646	2658.345	6000
4	0.549	0.0646	2658.345	6000
6	0.823	0.0646	2658.345	6000
8	1.098	0.0646	2658.345	6000
10	1.372	0.0646	2658.345	6000
12	1.647	0.0646	2658.345	6000
14	1.921	0.0646	2658.345	6000
16	2.195	0.0646	2658.345	6000
18	2.470	0.0646	2658.345	6000
20	2.744	0.0646	2658.345	6000
22	3.019	0.0646	2658.345	6000
24	3.293	0.0646	2658.345	6000
26	3.568	0.0646	2658.345	6000
28	3.842	0.0646	2658.345	6000
30	4.117	0.0646	2658.345	6000
32	4.391	0.0646	2658.345	6000
34	4.665	0.0745	3064.458	6000
36	4.940	0.0844	3472.879	6000
38	5.214	0.0894	3678.596	6000
40	5.489	0.0912	3752.716	6000
42	5.763	0.0909	3741.640	6000
44	6.038	0.0893	3676.014	6000
46	6.312	0.0869	3576.265	6000
48	6.586	0.0840	3456.096	6000
50	6.861	0.0808	3324.726	6000
52	7.135	0.0775	3188.350	6000
54	7.410	0.0741	3051.110	6000

56	7.684	0.0709	2915.740	6000
58	7.959	0.0677	2784.008	6000
60	8.233	0.0670	2756.057	6000
62	8.507	0.0672	2763.740	6000
64	8.782	0.0668	2749.280	6000
66	9.056	0.0661	2718.373	6000
68	9.331	0.0650	2675.386	6000
70	9.605	0.0638	2623.669	6000
72	9.880	0.0624	2565.802	6000
74	10.154	0.0608	2503.772	6000
76	10.428	0.0593	2439.109	6000
78	10.703	0.0577	2372.987	6000
80	10.977	0.0560	2306.308	6000
82	11.252	0.0544	2239.758	6000
84	11.526	0.0528	2173.858	6000
86	11.801	0.0513	2108.996	6000
88	12.075	0.0497	2045.461	6000
90	12.350	0.0482	1983.458	6000
92	12.624	0.0467	1923.133	6000
94	12.898	0.0453	1864.581	6000
96	13.173	0.0439	1807.859	6000
98	13.447	0.0426	1752.995	6000
100	13.722	0.0413	1699.993	6000



N05-A Pipeline & Spoolpiece – Basic Design

Basis of Design Pipeline & Tie-in Spools

DOCUMENT NUMBER:

N05A-7-10-0-70028-01

Rev.	Date	Description	Originator	Checker	Approver
01	15-01-2020	Issued for Comments	HvH	PF	PF
02	17-03-2020	Issued for Approval	PF	EvW	PF

Client

ONE-Dyas B.V.

Project

ONE-Dyas N05A Pipeline & Spool piece – Basic Design

Document

Basis of Design Pipeline & Tie-in Spools

Project number	19018
Document number	N05A-7-10-0-70028-01
Revision	02
Date	17.03.2020

Revision History

Revision	Description
01	Initial Issue – For Client comments
02	Client comments incorporated

Revision Status

Revision	Description	Issue date	Prepared	Checked	Enersea approval	Client approval
01	For Client Comments	15-01-2020	HvH	PF	PF	
02	For Client Approval	17-03-2020	PF	EvW	PF	

Table of content

1. Project Introduction

1.1. Project Introduction

One-Dyas plans to develop a successfully drilled well in block N05-A of the North Sea Dutch Continental Shelf. More wells will be drilled at this location through the same jacket. It is planned to develop the wells by installing a platform and a gas export pipeline with a connection to the NGT pipeline @KP142.1. The approximate length of the pipeline is 14.7 km.

In addition, a power cable will be installed from the Riffgat Windpark to the N05-A platform.

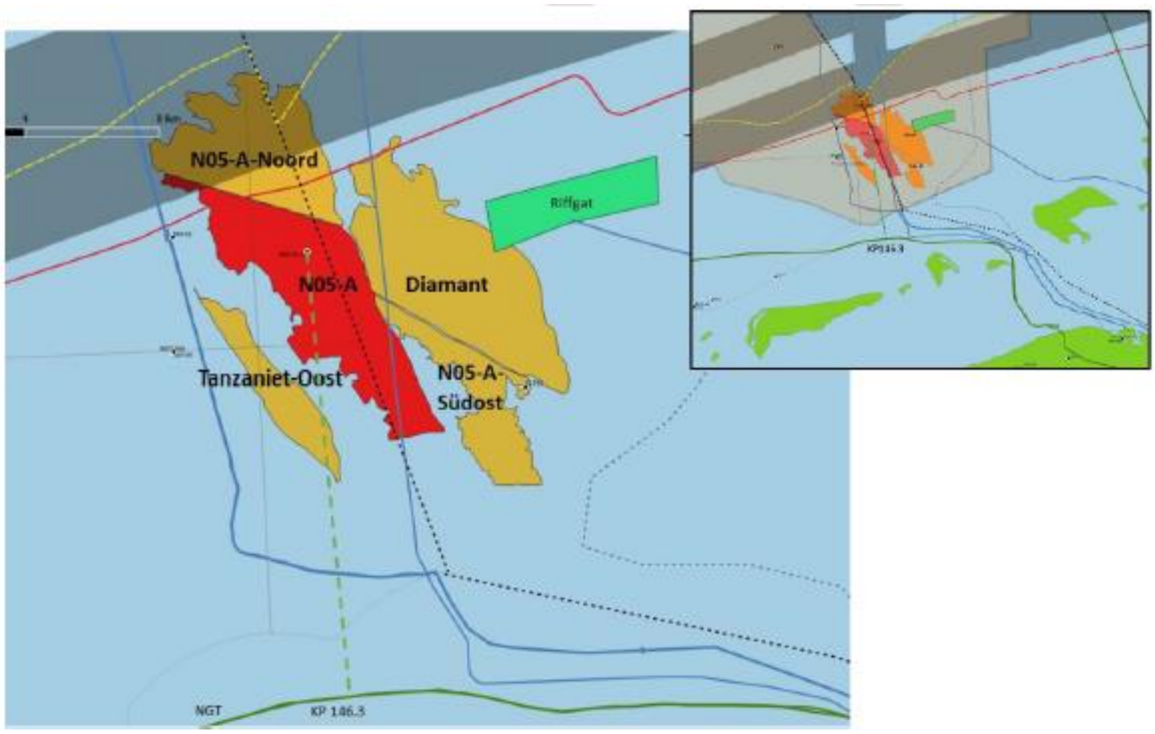


Figure 1: N05-A Field layout

1.2. Purpose Document

The Basis of Design defines the methodology and design data to be used throughout the flowline design from the new N05A platform to the connection to the NGT pipeline @KP142.1. This document is to be read in conjunction with documents as listed below in order of precedence.

Number	Title
N05A-7-10-0-70026-01-01	N05-A Pipeline Design – Basis of Design Flow Assurance

The following engineering items are described in subsequent sections of this Basis of Design report:

- Regulations, Guidelines and Specifications
- Pipeline Routing
- Seabed Geology
- Materials and Corrosion Protection
- Operational and Product Data
- Environmental Data
- Design Philosophy & Criteria

1.3. System of Units

All dimensions and calculations shall be documented using the International System of Units (SI) unless noted otherwise.

1.4. Abbreviations

BoD	Basis of Design
CWC	Concrete Weight Coating
FEA	Finite Element Analysis
LAT	Lowest Astronomical Tide
MTO	Material Take Off
PUF	Poly Urethane Foam
TB	Target Box
TOP	Top of Pipe
VIV	Vortex Induced Vibrations

2. Regulations, Guidelines and Specifications

The references, codes, regulations, guidelines and specifications used throughout the project are outlined in the following sections.

2.1. Regulations, Codes, Standards and Guidelines

[1] NEN3656:2015 "Eisen voor stalen buisleidingsystemen op zee" December 2015

[2] DNV-OS-F101. "Submarine Pipeline Systems." October 2013.

[3] DNV-RP-F105. "Free Spanning Pipelines." June 2017.

[4] DNV RP-F107. "Risk Assessment of Pipeline Protection." May 2017.

[5] DNV-RP-F109. "On-Bottom Stability Design of Submarine Pipelines." May 2017.

[6] DNV-RP-F110. "Global Buckling of Submarine Pipelines. Structural Design due to High Temperature/High Pressure." April 2018.

[7] DNV-RP-C203. "Fatigue Design of Offshore Steel Structures." April 2016.

[8] -

[9] DNV-RP-F114. "Pipe-soil interaction for submarine pipelines." May 2017.

[10] 21. American Lifelines Alliance. "Guidelines for the Design of Buried Steel Pipe. ASCE July 2001.

[11] ASME Boiler and Pressure Vessel Code. Section VIII Rules for Construction of Pressure vessels. Division 1. July 2013.

[12] Design of Submarine Pipelines Against Upheaval Buckling OTC 6335 by A.C. Palmer e.a. May 1990

[13] ISO 15589-2. "Petroleum petrochemical and natural gas industries — Cathodic protection of pipeline transportation systems - Part 2: Offshore pipelines" 2nd edition - 2012

[14] NEN-EN 1993-1-8 – Design of Steel Structures

[15] NEN-EN-ISO 19902 – Fixed Steel Offshore Structures

[16] ASME N16.9-2001 – Factory made wrought buttwelding fittings

2.2. Project Reference Documents

[I] N5-1-10-0-10000-01, Statement of Requirements for Platform N05-A

[II] Metocean Criteria for the N05A Platform – 181892_1_R2

[III] Metocean Criteria for the N05A Platform Side Tap - 191146_1_R2

[IV] Pipeline Bathymetry: LU0022H-553_DR-007_PR_1-4_v1.0 / 2-4 / 3-4 / 4-4

[V] N05A-7-10-0-70018-01, N5A-Development-Pipeline Route and Platform Area Survey R1

[VI] N05A-7-10-0-70020-01, Environmental Baseline Survey Report 1.0

[VII] N05A-7-10-0-70027-01-03 Flow Assurance Design Report

[VIII] N05A-7-10-0-70036-01-01 Flow Assurance Design Report -transient analysis

[IX] N05A-7-10-0-70031-01-01 Route Selection Report

[X] LU0022H-553-RR-03-2.1 N5a Lab Test Results Report

[XI] N5A VC-C-7 S-3 0300m CID

[XII] N5A VC-P-3 S-2 0405m CID

[XIII] N5A VC-P-8 S-4 0240m CID

3. Design Parameters

This chapter describes the design data to be considered for the pipeline (incl. spool pieces near the riser and the hot tap) from the new N05A-Platform to the NGT pipeline.

3.1. Pipe Data

The basic line pipe design and spool piece data to be considered in the analysis for the export gas line are presented in Table 3-1. Steel material properties considered in the design are presented in Table 3-2.

Property	
Product transported	Natural gas (dry)
Design life (years)	25
Approx. length (km)	14.7
Material grade	L360 NB
Manufacturing process	HFIW
Pipe outside diameter (")	20"
Pipe outside diameter (mm)	508
Pipe internal diameter	466.76
Wall thickness (mm)	20.62 (Sch60)
Wall thickness tolerance (%)	7.3
Wall thickness tolerance (mm)	+/- 1.5mm
Internal corrosion allowance (mm)	3
Anti-corrosion coating	3LPP
Anti-corrosion coating thickness (mm)	3
Anti-corrosion coating density (kg/m^3)	930
(Concrete) weight coating thickness (mm)	t.b.d
concrete weight coating density (kg/m^3)	3300
Minimum hot bend radius (mm)	2540 (5D)

Table 3-1 Pipeline data

Property	
Material	L360NB
Density (kg/m3)	7850 kg/m^3
Specified Minimum Yield Strength at 20°C (MPa)	360
Specified Minimum Yield Strength at 50°C (MPa)	360
Specified Minimum Tensile Strength (MPa)	460
Young's modulus (Pa)	2.07×10^{11}
Poisson ratio (-)	0.3
Thermal expansion coefficient (m/m·ºC)	1.17×10^{-5}

Table 3-2 Material properties

3.2. Process conditions

Table 3-3 presents the pipeline and spool design process parameters considered in the analysis.

Property	Export gas line
Design pressure	111.1 bar(g)
Operating pressures	95 bar(g)
Design temperature (min / max)	-20 °C / 50 °C
Operating temperature (min / max)	1 / 43 °C
Ambient (air / surface) temperature	-6.8°C / +24.2 °C
Content density (arrival, nominal operation)	88.7 / 96.1 kg/m³
Design flowrate (min/max)	0.14 / 6.0 MMNm3/d

Table 3-3 Process design parameters

Figure 3-1 shows the operational thermal profile along the pipeline, ref. [vii] .

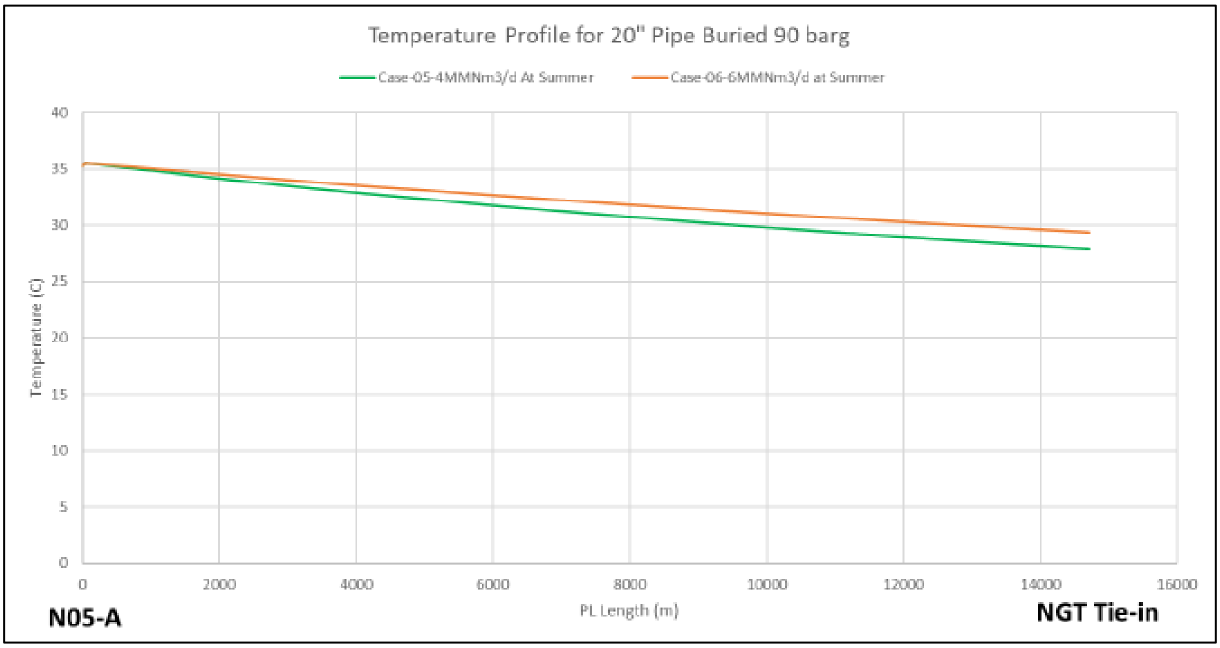


Figure 3-1 Operational thermal profile, nominal operation in summer

3.3. Coating Material Properties

Typical material properties of the coating are given in Table 3-4.

Property	Value
Anti-corrosion material type	3LPP
Anti-corrosion coating density	930 kg/m³
Anti-corrosion coating thermal conductivity	0.22 W/m°C
Anti-corrosion coating specific heat capacity	2000 J/kg°C

Table 3-4 Steel pipe coating material properties

3.4. Flange Properties

Table 3-5 presents the flange classes and main characteristics. The flange loads will be checked by using the ASME BPVC [10] flange integrity check. Note that table 3-5 is applicable to all flanges on the flowline and spool pieces.

Property	Export gas line
Flange rating	ANSI/ASME Class 1500
Flange type	RTJ Swivel / Weld Neck
Weld end thickness	20.62mm

Table 3-5 Flange properties

3.5. Environmental data

For the design of the pipeline, environmental data has been taken from Ref. [II] and [III]. Where Ref [II] contains the metocean data for the platform (water depth 26 m); Ref [III] contains the Metocean data for the NGT tie-in (water depth 8 m) target box. Tables 3-6 to 3-11 present the relevant metocean data for the 1 and 100 year design conditions for the applicable locations.

Property	1-year return period	100-year return period
Positive surge (m) @26m	1.58	3.04
Negative surge (m)	-1.02	-1.79
LAT with respect to MSL (m)	-1.41	
HAT with respect to MSL (m)	1.31	

Table 3-6 Near platform extreme water level data [ref. II]

Return Period Depth Level	Extreme Cs [m/s] Direction [towards]								OMNI
	N	NE	E	SE	S	SW	W	NW	
1-year									
Near-surface	0.36	0.94	0.98	0.70	0.42	0.77	0.98	0.59	0.98
Mid-Depth	0.40	0.89	0.90	0.53	0.27	0.62	0.90	0.51	0.90
Near-bed	0.38	0.74	0.74	0.42	0.25	0.56	0.74	0.43	0.74
100-years									
Near-surface	0.46	1.21	1.27	0.91	0.55	1.00	1.27	0.76	1.27
Mid-Depth	0.51	1.15	1.16	0.68	0.35	0.79	1.16	0.66	1.16
Near-bed	0.49	0.95	0.96	0.55	0.32	0.72	0.96	0.55	0.96

Table 3-7- Near platform design current data [ref. II]

Return Period Direction [from]	Hs [m]	Tz [s]	Tp [s]	Cmax [m]	Hmax [m]	THmax [s]	U_{1m} [m/s]
1-year							
North	5.3	9.2	11.7	5.9	9.3	9.5	1.67
North-east	3.8	6.8	8.3	4.3	6.7	8.5	1.04
East	2.6	5.2	6.6	3.0	4.7	7.5	0.55
South-east	2.1	4.6	5.2	2.3	3.6	6.9	0.34
South	2.4	4.7	5.2	2.8	4.3	7.3	0.48
South-west	3.2	5.6	6.2	3.6	5.6	8.0	0.78
West	4.7	8.0	10.5	5.3	8.3	9.1	1.43
North-west	6.5	9.9	12.4	7.3	11.4	10.1	2.19
100-years							
North	8.1	11.5	14.3	9.1	13.8	10.8	2.73
North-east	5.9	8.1	10.4	6.6	10.0	9.7	1.84
East	4.0	5.9	8.2	4.5	6.9	8.6	1.07
South-east	3.1	4.9	6.0	3.5	5.4	7.9	0.71
South	3.7	5.0	6.0	4.2	6.4	8.4	0.95
South-west	4.9	6.4	7.3	5.5	8.3	9.1	1.43
West	7.2	9.8	12.9	8.1	12.3	10.4	2.40
North-west	9.9	12.3	14.9	11.1	16.9	11.5	3.20

Table 3-8 Near platform design wave data [ref. II]

Property	1-year return period	100-year return period
Positive surge (m) @26m	1.48	2.72
Negative surge (m)	-0.90	-1.26
LAT with respect to MSL (m)	-1.89	
HAT with respect to MSL (m)	1.61	

Table 3-9 Near tie-in extreme water level data [ref. III]

Return Period Depth Level	Extreme Cs [m/s] Direction [towards]								Omni
	N	NE	E	SE	S	SW	W	NW	
1-year									
Surface	0.31	0.52	1.04	0.51	0.27	0.50	1.04	0.59	1.04
Mid-depth	0.30	0.50	1.01	0.44	0.25	0.43	1.00	0.55	1.01
Near-bed	0.26	0.45	0.89	0.23	0.10	0.19	0.61	0.39	0.89
100-years									
Surface	0.37	0.63	1.25	0.62	0.32	0.60	1.25	0.71	1.25
Mid-depth	0.36	0.60	1.21	0.53	0.31	0.52	1.20	0.66	1.21
Near-bed	0.33	0.57	1.12	0.29	0.13	0.23	0.77	0.49	1.12

Table 3-10 Near tie-in design current data [ref. III]

Return Period Direction [from]	Hs [m]	Tz [s]	Tp [s]	Cmax [m]	Hmax [m]	THmax [s]	U_{1m} [m/s]
1-year							
North	3.6	6.2	10.3	3.3	4.8	7.5	1.2
North-east	2.2	4.9	7.7	2.0	2.9	6.5	0.6
East	1.6	3.9	5.0	1.5	2.2	5.9	0.4
South-east	1.5	3.6	3.7	1.4	2.0	5.8	0.3
South	1.4	3.5	3.9	1.3	1.9	5.7	0.3
South-west	2.0	4.1	4.5	1.9	2.7	6.3	0.5
West	3.0	5.7	10.2	2.8	4.1	7.2	0.9
North-west	3.9	6.4	12.1	3.6	5.2	7.7	1.3
100-years							
North	3.9	6.4	10.6	4.2	5.7	7.9	1.5
North-east	2.4	5.1	7.9	2.6	3.5	6.8	0.8
East	1.7	4.1	5.2	1.9	2.6	6.2	0.5
South-east	1.6	3.7	3.8	1.8	2.4	6.1	0.4
South	1.6	3.7	4.1	1.7	2.3	6.0	0.4
South-west	2.2	4.3	4.6	2.4	3.2	6.7	0.7
West	3.3	6.0	10.7	3.6	4.9	7.5	1.2
North-west	4.2	6.6	12.6	4.5	6.2	8.1	1.6

Table 3-11 Near tie-in design wave data [ref. III]

3.6. Marine growth

The following marine growth has been assumed, in accordance with NEN 3656 [1]

From	To	Thickness	Density
+2m LAT	Seabed	50mm	1300 kg/m3

Table 3-12 Assumed marine growth properties

3.7. Geotechnical data

The survey report – N5A to NGT Hottap [ref. IV] indicates the soil along the route as ‘fine to medium Sand, with occasional areas of coarse Sand and Clay with gravel and shell fragments. Three lab result reports [ref XI – XII] present the soil parameters for the sand in the trajectory. The soil properties are listed in Table 3-13, data has been taken from ref. X-XIII and recommended values as per NEN3656 table H.1 ref[1] based on the soil description as presented in [ref X]. A SBP data example of the north end of the proposed route is presented in figure 3-14.

Soil type	Applicable area	Submerged Unit Weight (kN/m³)	Angle of internal friction (°)
Medium sand (measured)		10.2-10.5	32.5-34.9
Medium sand	Pipe on surface	10	32.5
	Trench backfill	8.5	28
Rock dump	Crossing / Tie-in	10	40

Table 3-13 Assumed soil geotechnical properties

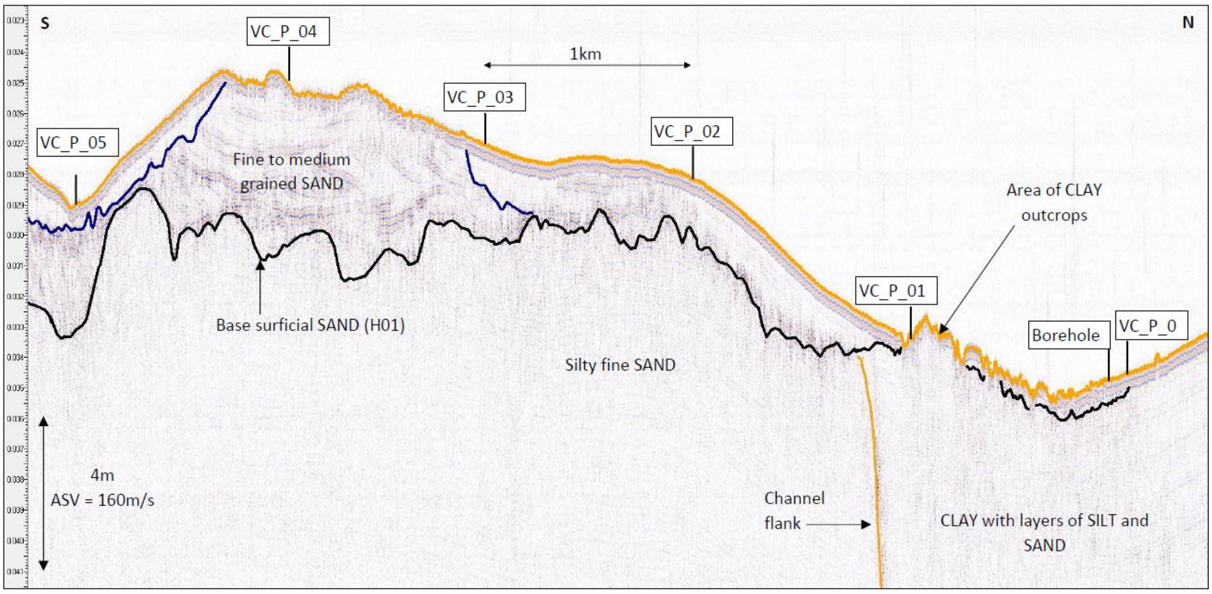


Figure 3-2 Soil profile from KP 0.0 to KP 6.0

4. Pipeline route data

This chapter deals with the pipeline route data describing the starting and end point of the pipeline, the used coordinate system, pipeline route coordinates and key facilities as well as the route bathymetry and contacts detected along the pipeline route. Based on this info the most optimal pipeline routing has been selected (ref. [IX].

4.1. General

The new pipeline to be installed originates at the new N05-A Platform and terminates at the NGT platform via a dedicated tie-in connection. The pipeline length is approx. 14.7 km.

An installation of the pipeline on top of the seabed has been indicated as an opportunity. The final cover height, or required concrete coating thickness will be determined based on the results of a risk assessment study, the on-bottom stability analysis and the upheaval buckling analysis.

Two pipeline/cable crossings are foreseen along the route. An overview of the field lay out is given in Figure 4-1.

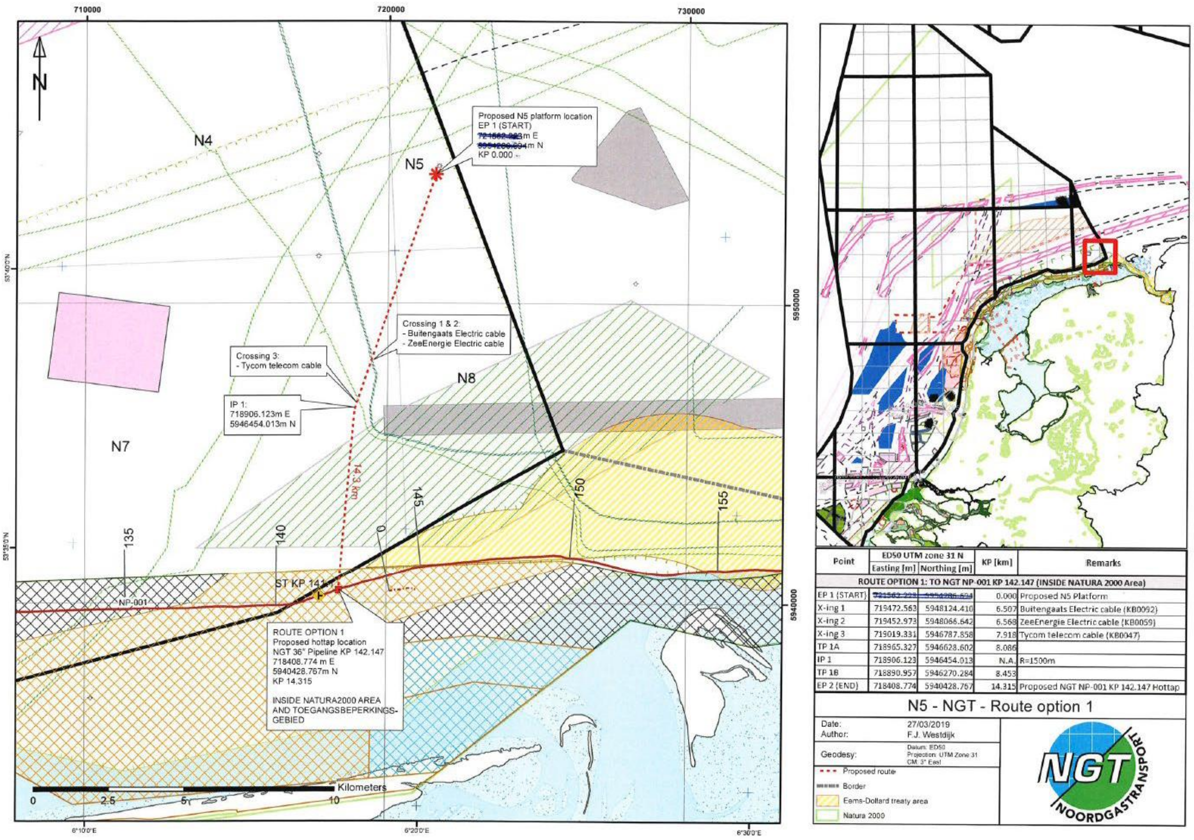


Figure 4-1 Overview N05A platform to the tie-in location

4.2. Coordinate system

The parameters of the geodetic system to be used for horizontal positions are listed in Table 4-1.

Item	Value
Datum	European Datum 1950 (ED50)
Projection	ED50 / UTM zone 31 N
Ellipsoid name	International 1924
Semi major axis	6 378 388 m
Inverse flattening	297.000
Central Meridian	03°00"00' E
Latitude of Origin	00°00"00' N
False Northing	0 mN
False Easting	500 000 mE
Scale Factor	0.9996

Table 4-1: Geodetic parameters

The vertical position is given relative to the Lowest Astronomical Tide (LAT).

4.3. Key facility coordinates

The following platform and tie in locations have been derived from Ref. [V] and are presented in Table 4-2.

Item	Northing (m)	Easting (m)
N05A Platform target box	5 954 608	721 622
NGT target box	5 940 549	718 738
NGT hot tap location KP142.1	5 940 532	718 766
Water depth at N05A Platform	26 m LAT	
Water depth at NGT hot tap	9.8 m LAT	

Table 4-2 Key Facility coordinates

4.4. Bathymetry

Figure 4-3 shows the bathymetry along the surveyed flowline route. The water depths recorded during survey along the proposed N05-A platform and the NGT pipeline hottap location ranges between 9.8 m LAT and 26.4 m LAT.

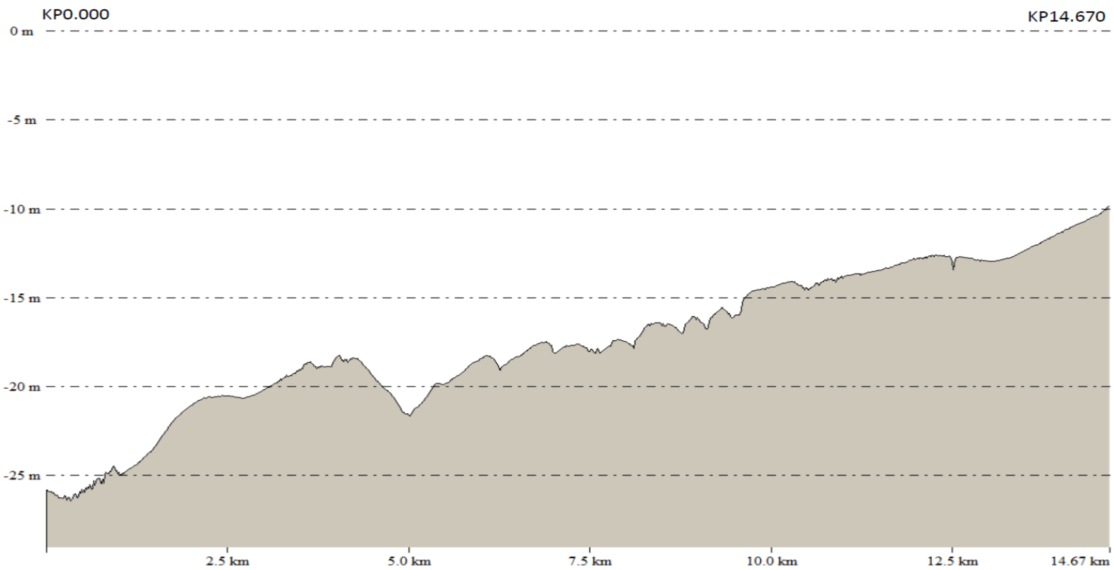


Figure 4-3 Seabed profile along pipeline route from P11-Unity Platform to Wye

4.5. Side Scan Sonar Contacts & Magnetometer Anomalies

Ref. [5] describes the seafloor sediments across the N05-A to the proposed NGT hottap location survey area to consist of a top layer of fine to coarse sand, with occasional areas of coarse sand and clay with gravel and shell fragments. Photographs taken along the proposed route show the presence of small ripples covering the majority of the seabed within the survey corridor area.

Numerous boulders and items of debris are observed in the survey area. Most of the boulders occur in the north of the survey area and coincide with areas of clay exposure.

4.5.1. Magnetometer Contacts

A total of 241 magnetic anomalies (appendix A) were picked within the surveyed N05-A platform to the 36” NGT Tie-in and N05-A platform to Riffgat Tie-in route corridor. Most of these anomalies can be attributed to unknown identified seabed features the following seabed infrastructures are known, one (1) pipeline and four (4) cables. However, one (1) unknown linear feature.

The following existing pipelines and cable are detected:

- 36” Pipeline from L10-AR to Uithuizen
- Tycom Telecom cable
- Buitengaats Power cable
- Zeeenergie Power cable
- Norned Power cable

4.5.2. Geophysical Data

Eight-Hundred-Thirty (830) side scan sonar contacts were observed within the route survey. Most of the contacts are boulders located around the N05-A platform and stretching to the east side to Riffgat, besides the bolders the following contacts are found, twenty-six (26) debris items, two (2) wrecks. Side scan sonar data can be found in Appendix A.

4.6. Cable & Pipeline Crossings

The following crossings along the pipeline route are envisaged:

Infrastructure Name	KP	Northing (m)	Easting (m)
Buitengaats Electric cable	6.412	719 346	5 948 729
ZeeEnergie Electric cable	6.487	719 327	5 948 655
Tycom Telecom Cable Hunmanby GAP - Eemshaven	8.180	718 915	5 947 014

*) The N05A Pipeline will be connected to the NGT Pipeline with a Hot tap. This hot tap is not part of the scope of the design report.

4.7. Approach

Near the platform a T-piece will be installed including 2 ball valves for the purpose of a future pipeline connection. At the NGT tie-in location 2 ball valves and a check valve will be placed for tie-in purposes. Figures 4-4 and 4-5 present an overview of respectively the platform and the tie-in location.

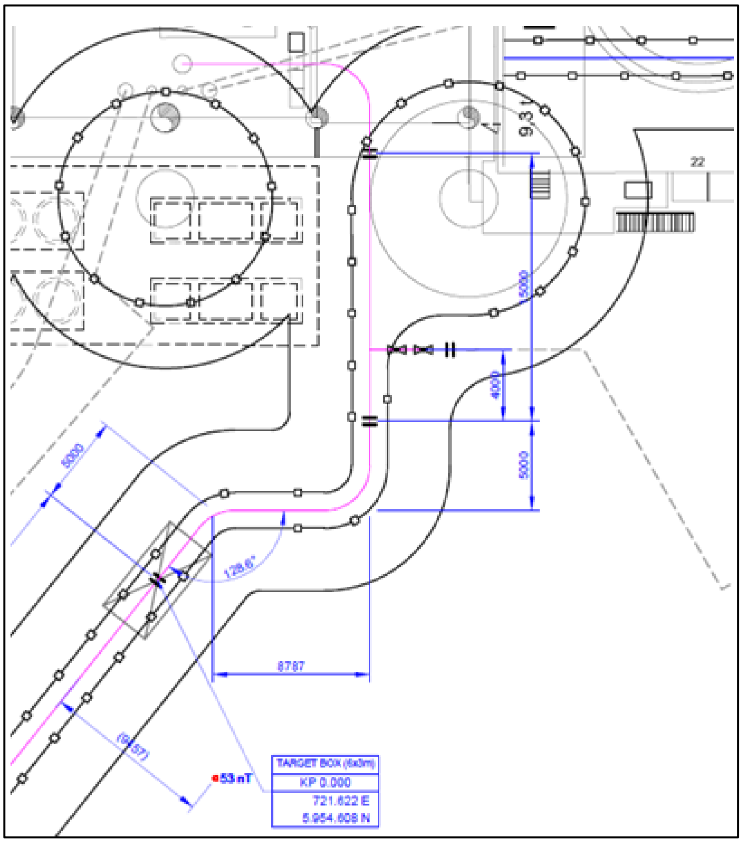


Figure 4-4 approach layout near the platform

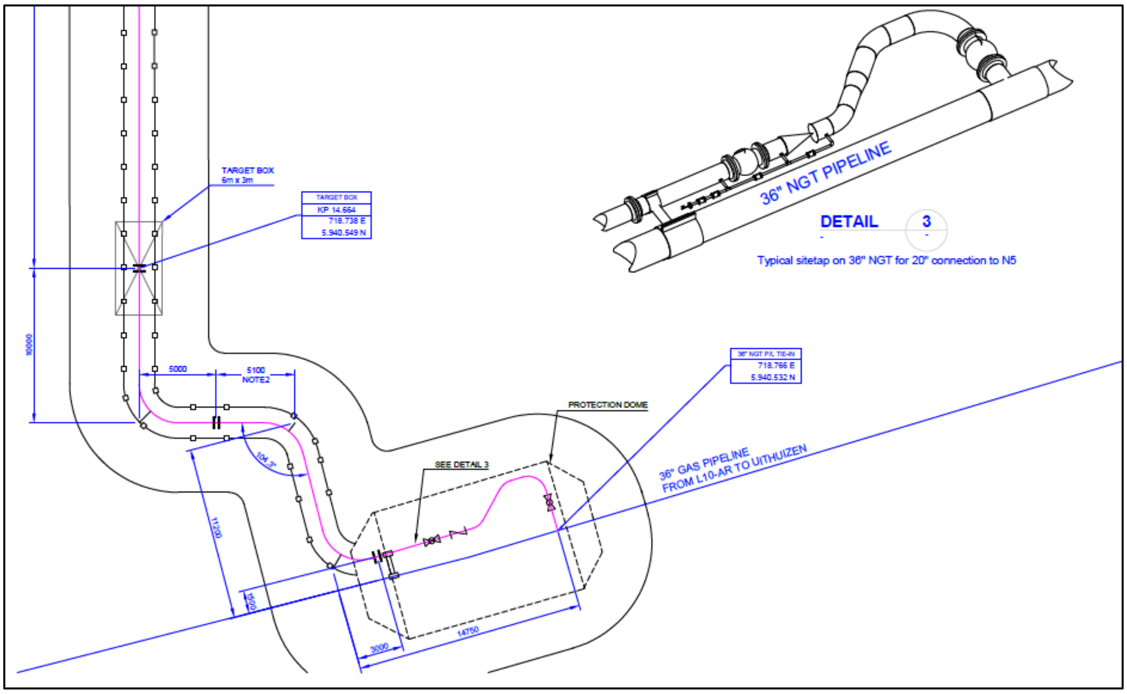


Figure 4-5 approach layout near the tie-in

5. Riser and Spool piece analysis

The purpose of the riser and expansion spool analysis at the N05A platform is to determine the combined effect of functional and environmental loads on the structural integrity of the system. The analysis consists of the stress analysis of the spool pieces on both ends of the pipeline, carried out in accordance with NEN 3656:2015 (Nederlands Normalisatie-instituut, 2012).

5.1. Stress Criteria

Stresses in the riser and tie-in spool pieces will be assessed by using the finite element software ANSYS. The analysis ensures the structural integrity of the riser/spool system by NEN 3656 (Ref. [1])

The analysis will account for the load history of the pipe over the design life by considering the following four load cases:

- Installation
- Hydrotest
- Operational – Nominal
- Operational – Corroded

Considering the design cases listed above the following design loads will be considered when performing the stress analysis, see Table 5-1.

Load	Installation	Hydrotest	Operation
Pressure	N/A	Hydrotest Pressure	Design Pressure
Temperature	Seawater Temperature	Seawater Temperature	Design Temperature
Internal Fluid	Seawater	Seawater	Product Filled
Wall Thickness	Nominal	Nominal	Nominal / Fully corroded
Hydrodynamic Loads	1-year wave + 1-year current	1-year wave + 1-year current	100-year wave + 100 year current
Pipeline End Expansion	N/A	Expansion Under Hydrotest Pressure	Expansion under design temperature and pressure

Table 5-1 Design loads

Calculated equivalent stresses for the various design conditions will be checked against the allowable stress values, as per NEN3656 (Ref. [1]), see Table 5-2.

Case	Load Combination As Per NEN3656 Table 3.	Limit Stress	Allowable Equivalent Stress (LB360)
Installation	LC1	$R_{e(\theta)} / \gamma_m$	327 MPa
Hydrotest	LC4	$0.85\ (R_e + R_{e(\theta)})/\ \gamma_m$	556 MPa
Operation (Nominal / Corroded)	LC4	$0.85\ (R_e + R_{e(\theta)})/\ \gamma_m$	556 MPa

Table 5-2 Applied stress limits

Where:

Re = specified minimum yield strength at 20ºC (N/mm^2).

$R_{e(\theta)}$ = the yield strength of the material at design temperature.

γ_m = material factor (for steel 1.1).

All design loads applied will be factored as per the requirements of NEN 3656 (Ref. [1]), see Table 5-3.

Loads	**Load factors for load combinations (a)**								
Load combinations	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6	LC 7a	LC 7b	LC 8
Internal pressure (design pressure)	-	1.25	-	-	-	-	1.0		1.0
Internal pressure (In combination)	-	-	-	1.15	1.15	-	-	1.0	1.15
Internal pressure (max. Incidental pressure)	-	1.10	-	-	-	-	-		1.1
Temperature differences (c g)	1.0	-	-	1.10	1.10	-	1.0	1.0	-
Soil parameters (d)	-	-	(d)	(d)	(d)	-	-	Low	-
Forced deformation (e)	-	-	1.1	1.1	1.1	1.1	-		-
Own weight	1.1	-	1.1	1.1	1.1	1.1	1.0		1.0
(Possible) coating (h)	1.2	-	1.2	1.2	1.2	1.2	1.0	1.2	1.0
Pipe contents (h)	1.1	-	1.1	1.1	1.1	1.1	1.0	1.1	1.0
Installation loads (f)	1.1	-	1.10	-	-	1.1	-		-
Hydrostatic pressure	1.1	-	1.1	1.1	1.1	1.1	1.0	1.1	
Marine growth (h)	-	-	1.2	1.2	1.1	-	1.0	1.0	1.0
Hydrodynamic forces	1.1	-	1.2	1.2	1.1	1.1	1.0	1.2	1.0
(a)	If a load has a favorable influence on the considered case this will not be considered if the load is variable and for a permanent load a multiplication factor of 0.9 is applied.								
(b)	The maximum incidental pressure does not need to be checked separately however must be ascertained by the pressure control sys-tem.								
(c)	During calculations of stress variations caused by temperature differences the highest and lowest occurring operation temperature should be considered. The displacements loads and moments exerting on connected equipment and/or structures are to be considered based on the design temperatures i.e. the temperature difference between the installation temperature and the maximum operational temperature.								
(d)	Reference is made to ref. [1] – K.4 to determine load spreading factors								
(e)	Forced deformations can be caused by: settling differences trench roughness execution sacking differences deformations due to pre-vented thermal expansion distortions in horizontal drilling and bottom-tow installation.								
(f)	Examples of installation loads are those applied during pipelay tie-ins trenching landfalls and HDD etc.								
(g)	Combined with measurements.								
(h)	In the stability check (BC 7b) the most unfavorable combination must be chosen. If necessary divide by the relevant factor.								

Table 5-3 Load factors

A description of the load combinations is shown below;

LC 1: Installation

LC 2: Only internal pressure, operating pressure, incidental pressure

LC 3: External load with zero internal pressure

LC 4: External load with internal pressure and temperature difference

LC 5: Variable load (primarily static load, e.g., temperature changes and pressure)

LC 6:a External pressure, external load and internal pressure zero

LC 7a: Incidental load (other than internal pressure)

LC 7b: Incidental load (meteorological)

LC 8: Dynamic loading

5.2. Model description

The riser and spool pieces will be modelled by using ANSYS dedicated submerged pipe element "PIPE59". This element is a uniaxial element with tension-compression, torsion, and bending capabilities and can account for internal pressure effects. The element is a 3D element with six degrees of freedom, translations in the x, y and z directions and rotations about the x, y and z axes. In addition the element accounts for buoyancy, wave and current loads, and is capable of large deflections and rotations.

Hot bends are modelled by using "PIPE18" elements which are elastic bend pipe elements with similar properties as the straight "PIPE59" elements described previously.

At riser clamp locations pipe nodal translation and/or rotations shall be constrained appropriately based on the physical constraints provided by the clamps (guide clamps / anchor clamps).

To incorporate pipeline end expansion into the spool pieces a representative pipeline length (greater than the anchor length) will be modelled. Note that conservatively seabed undulations are neglected while modelling these pipeline sections as this provides the greatest end expansion into the spool pieces.

Pipe-soil interaction is simulated using three independent non-linear spring elements (COMBIN39) attached to each pipe element. The springs represent the soil frictional resistance in the axial and lateral directions and the soils bearing capacity in the vertical direction. As the spool piece will be rock dumped after the hydrostatic testing, additional non-linear springs representing the uplift resistance of the rockdump / trenched backfill material, are attached to the pipe elements for the "operational" load cases. A detailed description of how the pipe soil interaction will be modelled is provided separately in section 5.3.

5.3. Pipe-soil interaction

The characteristics of the springs, which simulated the pipe-soil interaction, are defined through non-linear force-deflection curves. The force-deflection curves describe the frictional restraint provided by the soil to the pipeline in the axial and lateral direction and the soil's bearing capacity / upwards resistance in the vertical direction. The upcoming sections describe how the force-deflection curves of the springs are generated.

5.3.1. Exposed pipeline – axial soil resistance

The axial soil resistance for a pipeline / spool piece resting on the seabed, per meter pipe-length, is a function of the pipe submerged weight (vertical load) and the axial Coulomb friction coefficient. The axial friction is determined as follows:

$$F_{axial} = \mu_{Coulomb} w_s$$

Where:

- F_{axial} = Peak axial soil resistance [N/m]
- $\mu_{Coulomb}$ = Coulomb friction coefficient [-]
- w_s = Pipe submerged weight [N/m]

The axial restraint will be described through a bi-linear force-displacement relationship, as shown in Figure 5-1. The stiffness of the springs varies along the pipeline route and between load steps to account for variations in the pipe submerged weight and soil conditions.

The axial spring mobilization displacement is assumed to be 1.25 mm.

Figure 5-1 Axial resistance Force-Displacement curve

5.3.2. Exposed pipeline – lateral soil resistance

Lateral soil resistance is composed of two parts:

- Coulomb friction.
- Passive soil resistance due to the build-up of soil penetration (and hence a soil berm, as the pipe moves laterally).

To account for both components of resistance, an equivalent friction coefficient shall be used, which is defined as:

$$\mu_{equivalent} = \mu_{Coulomb} + \mu_{passive}$$

Where:

- μ_{eqv} = Equivalent lateral friction coefficient [-]
- $\mu_{Coulomb}$ = Coulomb friction coefficient [-]
- $\mu_{passive}$ = Passive soil resistance coefficient [-]

The passive soil resistance model proposed in DNV's Recommended Practice, DNV-RP-F109 (rev. [5]) will be used.

The passive soil resistance coefficient, for a pipeline resting on a sandy seabed, depends on the pipe penetration depth into the soil and can be determined by the formulation:

- $\mu_{passive} = \frac{F_R}{F_C} = (5\kappa_s - 0.15\kappa_s^2)\left(\frac{z_p}{D}\right)^{1.25}$ if $\kappa_s \leq 26.7$
- $\mu_{passive} = \frac{F_R}{F_C} = \kappa_s \left(\frac{z_p}{D}\right)^{1.25}$ if $\kappa_s > 26.7$

Where:

- F_R = Passive resistance force [N/m]
- F_C = Vertical contact force between pipe and soil [N/m]
- D = Pipe outside diameter, including all coatings [m]
- z_p = Total pipe penetration [m]
- κ_s = Soil parameter for sandy soils [-]
- γ'_s = Submerged unit soil weight [N/m^3]

The soil parameter for sand, κ_s, is determined as:

$$\kappa_s = \frac{\gamma'_s D^2}{F_C}$$

The total pipe penetration is taken as the sum of:

- Initial penetration due to self-weight.
- Penetration due to dynamics during laying.
- Penetration due to pipe movement under the action of waves and current.

The pipe static/initial penetration due to self-weight for pipelines resting on sandy soil will be determined using the following formula taken from DNV-RP-F109 (rev. [5]):

$$\frac{z_{pi}}{D} = 0.037{\kappa_s}^{-0.67}$$

Just as for the axial restraint, the lateral soil resistance will be described through a bi-linear force-displacement relationship as presented in Figure 5-1. The friction forces are increased monotonically to a maximum value calculated as the product of the pipe submerged weight (w_s) and the equivalent friction coefficient (μ_{eqv}), at a mobilisation distance of 2mm.

5.3.3. Vertical soil bearing capacity (Downward resistance)

The static vertical soil reaction per unit length can be determined based on bearing capacity formulas for ideal 2-D strip foundations, as per DNV-RP-F105 (rev. [3]):

$$R_V = \gamma'_{soil} B(N_q v_{eff} + 0.5 N_\gamma B)$$

Where:

- R_V = Vertical soil reaction [N/m]
- N_q & N_γ = Bearing capacity factors [-]
- v_{eff} = Effective penetration [m] (The larger of $v - D/4$ and 0)
- v = Vertical penetration [m]
- B = Contact width for pipe-soil load transfer [m]

The bearing capacity factors are determined as follows:

$$N_q = e^{\pi \tan \varphi_s} \tan^2\left(45 + \frac{\varphi_s}{2}\right)$$

Where:

φ_s = Angle of internal friction [°]

$N_\gamma = 1.5\left(N_q - 1\right) \tan \varphi_s$

The contact width for pipe-soil load transfer, B, is given by:

- $B = 2\sqrt{(D - v)v}$ if $v \le D/2$
- $B = D$ if $v > D/2$

5.3.4. Buried pipeline – axial soil resistance

Soil resistance forces for buried pipeline sections are based on ASCE's "Guidelines for the Design of Buried Steel Pipe" [9].

The maximum axial soil force that can be transmitted to the pipe per unit length is given by:

$$T_u = \pi D \alpha c + \pi D H \gamma'_s \frac{1 + K_0}{2} \tan \delta$$

Where:

- c = Soil cohesion representative of soil backfill material [N/m^2] (c=0 for sand)
- H = Depth to the pipeline centreline [m]
- K_0 = Coefficient of earth pressure at rest [-] $(1 - \sin \varphi_s)$
- α = Adhesion factor [-]
- δ = Interface angle of friction for pipe and soil [°] $(f\varphi_s)$
- f = Coating dependent factor relating the internal friction angle of the soil to the friction angle at the pipe soil interface.

The axial resistance mobilisation displacement, Δ_t, is determined considering the soil type as follows:

- Δ_t = 3mm for dense sand
- Δ_t = 5mm for loose sand
- Δ_t = 8mm for stiff clay
- Δ_t = 10mm for soft sand

5.3.5. Buried pipeline – lateral soil resistance

The maximum lateral force that the soil can transmit per unit pipe length is given by:

$$P_u = N_{ch} cD + N_{qh} \gamma'_s HD$$

Where:

- N_{ch} = Horizontal bearing capacity for clay (0 for c=0).
- N_{qh} = Horizontal bearing capacity factor for sand (0 for $\varphi_s = 0$)

The bearing capacity factors are taken from figure 5-2

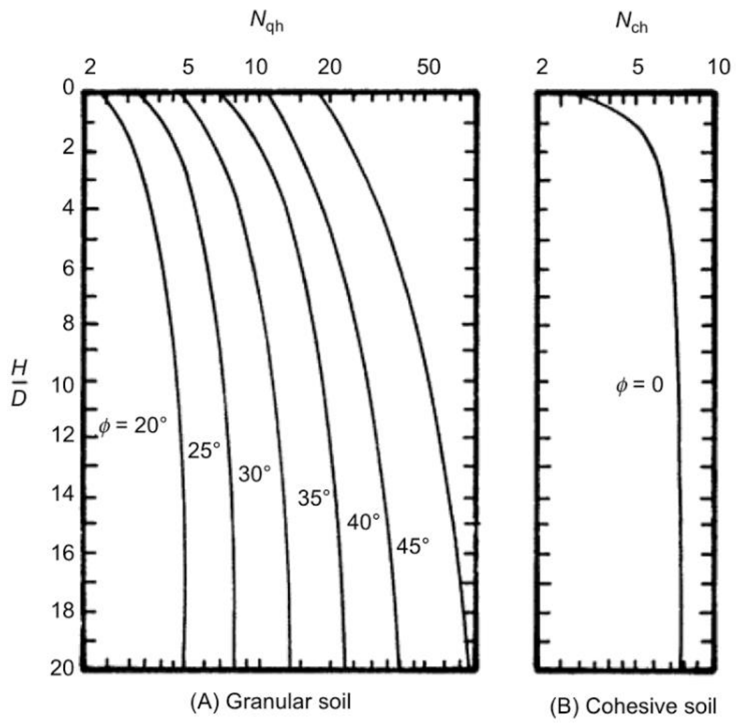


Figure 5-2 Horizontal bearing capacity factors

The lateral soil resistance mobilization displacement is given by:

$$\Delta_p = 0.04\left(H + \frac{D}{2}\right) \leq 0.10D \ to \ 0.15D.$$

5.3.6. Buried pipeline – vertical upward soil resistance

The uplift resistance R_{max} of a pipe in sand consists of two components, viz. a component owing to the weight of the soil above the pipe and a component owing to soil friction as per DNV-RP-F110 (rev. [6]). The uplift resistance can therefore be expressed as:

$$R_{max} = \left(1 + f\frac{H}{D}\right)(\gamma'_s HD)$$

The uplift resistance factor, f, is:

- $f = 0.1$ for loose sand (backfill)
- $f = 0.5$ for rockdump

The non-linear force-displacement response of a buried pipe is represented by a tri-linear curve as shown in figure 5-3.

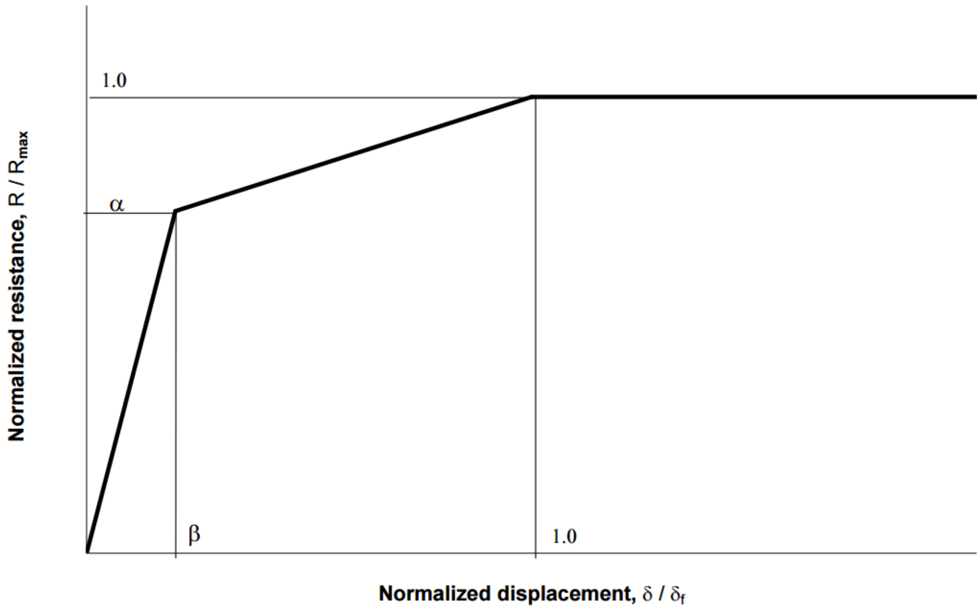


Figure 5-3 Uplift resistance Force-Deflection curve

Where:

- δ_f= Failure displacement (=0.0065H for loose sand backfill) (=20mm for rock dump)
- $\alpha = 0.8$ for loose sand (backfill) and $\alpha = 0.7$ for rock dump
- $\beta = 0.2$

5.4. Fatigue analysis

Fatigue is caused by time varying stresses resulting from applied loads to the riser and parts of the spool piece system which are exposed to hydrodynamic loads.

The riser and spool piece section are from approx. LAT +6.000m to seabed level exposed to the environment and hence are subjected to time varying loads. Three sources of time varying loads, and hence fatigue damage to the riser, are identified:

1. Vortex Induced Vibrations (VIV)
2. Direct wave loading
3. Indirect loads resulting from platform deflections

Riser guide clamps will be spaced such that the maximum span length is below the critical span length at which VIV can occur. The methodology for determining the critical span lengths are described in chapter 7 of this report.

To assess fatigue damage due to direct and indirect wave loading, platform deflections are applied, and the exposed riser section will be subjected to hydrodynamic drag and inertia forces. The drag and inertia forces are determined using the wave induced velocities and accelerations as experienced by the riser section over the lifetime of the pipeline system considering the ”Individual Wave Scatter Diagrams for Fatigue H-T” attached as appendix B.

To estimate the fatigue damage, due to direct and indirect wave loading, a detailed finite element assessment will be carried out considering the same finite element model of the riser spool system as described in Section 5.

In this case the H-T wave scatter diagram will be subdivided into a number of representative blocks, with a single sea-state selected to represent all waves in that block. For the wave height within a particular bin the mean wave height is selected and the corresponding wave period is based on the weighted average of the mean wave periods. This reduces the number of required finite element analyses. These wave blocks and the corresponding platform deflections based on the actual platform deflections will be applied to the model. The analyses will account for the directionality of the wave and the number of occurrences of the waves as per the scatter diagrams. The maximum longitudinal (= axial + bending) stress ranges are extracted from the riser elements as follows:

$$\Delta\sigma_{ax,max} = \Delta\sigma_{ax,pdeflect} + \Delta\sigma_{ax,wave} = 2 * \sigma_{ax,amplitude,pdeflect} + (\sigma_{ax,max,wave} - \sigma_{ax,min,wave})$$

Where:

- $\Delta\sigma_{ax,pdeflect}$ = Longitudinal stress range due to platform deflection [N/m^2]
- $\Delta\sigma_{ax,wave}$ = Longitudinal stress range due to wave [N/m^2]
- $\sigma_{ax,amplitude,pdeflect}$ = Single longitudinal stress amplitude due to platform deflection [N/m^2]
- $\sigma_{ax,max,wave}$ = Maximum longitudinal stress due to wave [N/m^2]
- $\sigma_{ax,min,wave}$ = Minimum longitudinal stress due to wave [N/m^2]

The allowable number of cycles will then be determined (N_p) in relation to the maximum longitudinal stress range in all riser elements ($\Delta\sigma_{ax,max}$) for each wave block given by:

$$\log N_p = \log a_n - m_n \log\left(\Delta\sigma_{ax,max}\left(t/t_{ref}\right)^k\right)$$

Where:

- N_p = Predicted number of cycles of failure for stress range [-]
- $\Delta\sigma_{eqv,max}$ = maximum stress range [N/m²]
- $\log a_n$ = Constant valid in the range n (see Table 5-4)
- m_n = Constant valid in the range n (see Table 5-4)
- t = Wall thickness [m]
- t_{ref} = Reference wall thickness (16mm)
- k = Thickness component (see Table 5-4)

S-N curve designation	N<=10⁶ cycles		N>10⁶ cycles		Fatigue limit at 10⁷ cycles	Thickness component (k)
	m_1	$\log(a_1)$	m_2	$\log(a_2)$		
F (seawater with cathodic protection)	3.0	11.455	5.0	15.091	41.52	0.00

Table 5-4. Fatigue curve parameters (ref. [6])

The design S-N curve (F-curve) is selected according to Table 2.5 of DNV-RP-C203, Ref [7] based on the expected maximum misalignment δ_m, see equation 2.10.5 of Ref [7]. The expected misalignment is calculated based on the pipe diameter/wall thickness and pipe tolerances (thickness and diameter) as given in Table 3.1.

The Stress Concentration Factor (SCF), to be used in the fatigue calculations for both the corroded and non-corroded wall thickness case, is shown in Table 5.5. They are calculated based on equations 2.10.4 and 2.10.1 of DNV-RP-C203, Ref [7].

Pipeline	Case	δ_m (mm)	SCF
20" Export Gas	Non corroded	2.12	1.25
20" Export Gas	Corroded	2.12	1.29

Table 5-5. Overview SCFs

The total fatigue damage due to direct wave loading and platform deflections is then determined, through summation using the Palmgren-Miner rule at each element in the riser as follows:

$$FD = \sum_1^k \left(\frac{n_i}{N_i}\right)$$

Where:

- k = Number of stress/wave blocks
- n_i = Number of stress cycles/wave occurrences in stress block i
- N_i = Number of cycles to failure at constant stress range in stress block i

The acceptability of the fatigue damage is then determined by comparison with the allowable fatigue damage (α_{fat}) ratio as given in Ref. [2]:

$$\alpha_{fat} \geq FD$$

Where:

α_{fat} = Allowable damage ratio = 0.1 [2]

5.5. Low cycle analysis

The riser and spool piece system will also be checked for low cycle fatigue, i.e. stress variations due to pressure and temperature fluctuations. During the pipeline's life time the following pressure/temperature fluctuations are anticipated:

- 1x strength test
- 3x leak tests (worst case)
- 25x shut down: Dp = 75 barg and temperature to ambient (annual shut down)

The allowable cycles for the resulting stress variations are to be determined from figure K.8 of ref. [1].

6. Wall Thickness Analysis

Several phenomena are to be investigated prior to finalising the selected wall thickness. Elements to be taken into account:

- pressure containment;
- on-bottom stability;
- implosion;
- progressive plastic collapse;
- local buckling;
- bar buckling;

6.1. Pressure containment

6.1.1. Design condition

NEN 3656, states that for every load combination the design resistance (R_d) must be greater than or equal to the loading effect (S_d) or:

$$R_d \geq S_d$$

R_d is defined as:

$$R_d = R_{e(\Theta)} / \gamma_m$$

Where:

$R_{e(\Theta)}$	=	yield strength of the material at design temperature (N/mm^2)
γ_m	=	material factor (1.1 for steel)

For load combination LC2 (internal pressure only), the equation for hoop stress can be expressed as:

$$\sigma_h = \frac{\gamma_p \cdot P_d \cdot (OD - t_{\min})}{2 \cdot t_{\min}}$$

Where:

s_h	=	hoop stress (N/mm^2)
γ_p	=	load factor as per Table 5-3 (-) => 1.25
Pd	=	design pressure (N/mm^2)
OD	=	outside diameter of steel pipe (mm)
t_{min}	=	minimum wall thickness (mm)

The selected wall thickness (t_{nom}) is then determined by:

$$t_{nom} = \left\{ \frac{t_{\min} + CA}{1 - f_{tol}} \right\}$$

Where:

CA	=	applicable corrosion Allowance (mm)
f_{tol}	=	fabrication tolerance (%)

Further to this, NEN 3656 specifies additional requirements for bends with a bending radius R_b < 10 OD, to adjust the hoop stress of straight pipe (torus effect).

$$S_h(bi) = \frac{2R_b - \frac{1}{2}OD}{2R_b - OD} \cdot S_h \quad \text{(for inside bend)}$$

$$S_h(bo) = \frac{2R_b + \frac{1}{2}OD}{2R_b + OD} \cdot S_h \quad \text{(for outside bend)}$$

6.1.2. Hydrostatic Testing

The hydrostatic testing of pipeline / riser systems has two objectives:

- verify the strength of the system
- verify that there are no leaks from the system

The test pressure, P_t, will be determined as per as per Section 10.18.3 of NEN 3656 (Ref. [1]).

$$P_{t.\min} = C_p \cdot P_d \cdot \frac{R_e}{R_{ev}}$$

Where:

C_p	=	pressure test coefficient (-) => 1.30 for gas lines; 1.25 for others
P_d	=	design operating pressure (N/mm^2)
R_e	=	minimum yield stress at 20 °C (N/mm^2)
R_{ev}	=	minimum yield stress at design temperature (N/mm^2)

The maximum hydrostatic test pressure is based on the weakest part of the pipeline/riser system to be tested. The pressure shall not exceed, $P_{t,max}$, which is defined by:

$$P_{t.\max} = \frac{2.R_e \cdot t_{\min}}{(OD - t_{\min})}$$

However, the maximum hydrotest pressure should not exceed the mill test pressure, which is given by:

$$P_{T,mill} = 0.9 \cdot \frac{2 \cdot R_e \cdot t_{nom}}{OD} \quad \text{and}$$

$$t_{nom} = \left\{ \frac{t_{\min} + CA}{1 - f_{tol}} \right\}$$

Where:

t_{nom}	=	nominal wall thickness (mm)
t_{min}	=	minimum wall thickness (mm)
CA	=	applicable corrosion Allowance (mm)
f_{tol}	=	fabrication tolerance (%)

6.2. On-bottom Stability

6.2.1. Introduction

The aim of the stability analysis is to verify that the submerged weight of the pipeline ensures lateral stability against environmental loading. Depending on the pipeline being buried or not, the on-bottom stability analysis is carried out for the following condition(s):

- Installation – flooded
- Installation – empty
- Operation – product filled

The pipeline is to be laterally stable on the seabed for a 1 year resp. 100 year return period environmental conditions for a buried resp. unburied pipe. A buried pipeline will not be subject to any environmental loading during hydrostatic testing and operation.

6.2.2. Hydrodynamic loads

Hydrodynamic loads arise from the relative motions between pipe and seawater. They consist of drag, lift and inertia forces.

The drag force F_D is given by:

$$F_D = C_D \cdot OD_{tot} \cdot \frac{1}{2} \cdot \rho \cdot V \cdot |V|$$

Where:

C_D	=	drag force coefficient (-)
OD_{tot}	=	total diameter of coated pipe (m)
ρ	=	mass density of surrounding fluid (kg/m^3)
V	=	velocity of the fluid normal to the pipe axis (m/s)

The lift force F_L is calculated by the following equation:

$$F_L = C_L \cdot OD_{tot} \cdot \frac{1}{2} \cdot \rho \cdot V^2$$

Where:

C_L	=	lift force coefficient (-)

The inertia force F_I is determined by the following equation:

$$F_I = \rho \cdot C_I \cdot \frac{\pi}{4} \cdot OD_{tot}^2 \cdot a$$

Where:

C_I	=	inertia force coefficient (-)
a	=	Fluid particle acceleration (m/s^2)

The recommended values of hydrodynamic coefficients for the on-bottom stability design as a function of the embedment of the pipeline are listed in Table 6-1.

Coefficient	Pipe embedment			Riser
	0%	**10%**	**20%**	
Drag	0.70	0.63	0.53	1.0
Lift	0.90	0.90	0.81	-
Inertia	3.29	2.80	2.30	2.0

Table 6-1 Overview hydrodynamic coefficients

The wave induced water particle velocities and accelerations will be determined using the appropriate wave theory for the design wave height, period and water depth. Phase shifts between horizontal and vertical water particle velocities will be considered.

6.2.3. Stability check

The stability of the pipelines is checked using the following relationship:

$$W_s > f_s \cdot \left(\frac{F_D + F_I}{f_w} + F_L \right) - \frac{F_P}{f_w}$$

Where:

W_s	=	pipeline submerged weight (N/m)
f_s	=	safety factor (-) => 1.1
F_D	=	drag force (N/m)
F_L	=	lift force (N/m)
f_w	=	friction factor (-)
F_I	=	inertia force (N/m)
F_P	=	passive soil resistance (N/m)

A safety factor (f_s) of 1.1 will be implemented. The above equation assumes absolute stability criteria. Note that the actual F_p is limited to the maximum of the combined drag and inertia forces.

The passive soil resistance is derived from:

$$F_p = 0.5 \cdot \rho_{soil} \cdot \varepsilon^2 \cdot K_p$$

Where:

ρ_{soil}	=	submerged soil density (kg/m^3)
ε	=	embedment of pipeline (m)
K_P	=	coefficient of passive soil resistance (-)

and K_P is calculated from :

$$K_P = \frac{1+\sin(\phi)}{1-\sin(\phi)} = \tan^2 \cdot \left(45 + \frac{\phi}{2} \right)$$

Where:

ϕ	=	angle of internal friction (°)

6.3. Implosion

6.3.1. External overpressure

The collapse pressure p_c causing implosion (radial instability) can be determined using:

$$(P_c - P_e) \cdot (P_c{}^2 - P_p{}^2) = P_c \cdot P_e \cdot P_p \cdot 2 \cdot \delta_0 \cdot \frac{D_g}{t}$$

Where:

D_g	=	nominal diameter of pipe (mm)
P_c	=	critical external pressure for collapse (N/mm2)
P_e	=	critical external pressure for elastic deformation (N/mm^2)
P_p	=	critical external pressure for plastic deformation (N/mm^2)
P_L	=	allowable external pressure (N/mm^2)
δ_0	=	initial deformation (mm)
t	=	nominal wall thickness (mm)

$$D_g = \frac{1}{2} \cdot \{OD_{nom} - (OD_{nom} - 2 \cdot t_{min})\}$$

The critical external pressure for plastic deformation is calculated from:

$$P_p = \frac{2 \cdot R_e \cdot t}{D_{nom}}$$

The critical external pressure for elastic deformation is calculated from:

$$P_e = \frac{2 \cdot E}{1 - \nu^2} \cdot (\frac{t}{D_{nom}})^3$$

Where:

ν	=	Poisson's ratio for elastic deformation (-) => 0.3

As a part of this the initial deformation is derived from:

$$\delta_0 = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}}$$

Where:

D_{max}	=	largest diameter of the ovalized pipe cross section
D_{min}	=	smallest diameter of the ovalized pipe cross section

The maximum allowable external pressure is defined as:

$$\gamma_{g,p} \cdot P_L \leq \frac{\gamma_M \cdot P_c}{\gamma_{m,p}}$$

Where:

$\gamma_{g,p}$	=	load factor (-) => 1.05
γ_M	=	model factor (-) => 0.93
$\gamma_{m,p}$	=	material factor (-) => 1.45

6.3.2. Bending moment

In case of a bending moment on the pipe, the moment which will cause buckling is calculated from the plastic moment of the pipe section.

$$M_c = D_{nom}{}^2 \cdot t \cdot R_e$$

The maximum allowable bending moment is defined as:

$$\gamma_{g,M} \cdot M_L \leq \frac{\gamma_M \cdot M_c}{\gamma_{m,M}}$$

Where:

$\gamma_{g,M}$	=	load factor (-) => 1.1
γ_M	=	model factor (-) => 1.0
$\gamma_{m,M}$	=	material factor (-) => 1.3
M_L	=	allowable bending moment for buckling (Nm)
M_c	=	critical bending moment for buckling (Nm)

6.3.3. Combined external pressure and bending moment

When external pressure exists in combination with a bending moment besides the checks above the condition for combined stresses as shown below shall be fulfilled.

$$\frac{\gamma_{g,p} \cdot P_L}{P_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,m} \cdot M_L}{M_c / \gamma_{m,M}} \right)^n \leq \gamma_M$$

Where:

$$n = 1 + 300 \cdot \frac{t}{D_{nom}}$$

Where:

$\gamma_{g,p}$	=	load factor for pressure (-) => 1.05
$\gamma_{g,m}$	=	load factor for bending (-) => 1.55
γ_M	=	model factor (-) => 0.93
$\gamma_{m,p}$	=	material factor for pressure (-) => 1.25
$\gamma_{m,M}$	=	material factor for bending (-) =>1.15
M_L	=	allowable bending moment for buckling (Nm)
M_c	=	critical bending moment for buckling (Nm)

6.4. Progressive plastic collapse

Progressive plastic deformation load cycle will lead to extreme deformation, collapse and cracks initiation through the wall.

The condition for avoiding buckle propagation is:

$$\varepsilon_{\max} = \alpha \cdot \Delta T \leq \left[\frac{R_{ev}}{E} \cdot \sqrt{1 - \frac{3}{4}\left(\frac{\sigma_h}{R_{ev}}\right)^2} + \frac{R_e}{E} \sqrt{0.9 - \frac{3}{4}\left(\frac{\sigma_h}{R_e}\right)^2} \right]$$

Where:

α	=	coefficient of linear thermal expansion (m/ m/ ° C)
ΔT	=	temperature differential [° C] (design – installation)

Parameters have to be factored as defined in section 6.

6.5. Local buckling

In accordance with NEN 3656, if OD / t < 55, an assessment on local buckling can generally be omitted.

For this project it would mean that a local buckling check is required for a wall thickness of maximum 5.0 mm, which will be much smaller than the anticipated wall thickness based on internal pressure and on-bottom stability. This will be checked during detailed design.

6.6. Bar buckling

In a free span the pipeline will be susceptible to bar buckling. Bar buckling may occur due to an effective axial compressive force (N) in the pipeline. The compressive force in an axially restrained pipeline is based on the longitudinal stress:

$$N = A \cdot (\nu \cdot S_h - \gamma_t \cdot E \cdot \alpha \cdot \Delta T)$$

Where:

A	=	cross sectional area of steel (mm^2)
ν	=	Poisson's ratio for elastic deformation (-) => 0.3
S_h	=	factored hoop stress (N/mm^2)
γ_t	=	load factor as given in Table 5-3 (-)
α	=	coefficient of thermal expansion (m/m/°C)
ΔT	=	pipeline temperature differential (° C) (design – installation)

The factored hoop stress (S_h) is calculated from:

$$S_h = \gamma_P \cdot \sigma_h$$

and

$$\sigma_h = \frac{P_d \cdot (OD - t_{\min})}{2 \cdot t_{\min}}$$

Where:

P_d	=	design pressure (N/mm^2)
t_{min}	=	minimum pipe wall thickness (mm)
OD	=	outside diameter of steel pipe (mm)
γ_P	=	load factor as given in Table 5-3 (-)

The buckling length is based on the Euler buckling load definition, defined in Ref. [3]. Bar buckling is avoided if the span length fulfils:

$$L \leq \sqrt{4 \cdot \pi^2 \frac{E \cdot I}{|N|}}$$

Where:

L	=	allowable span length (mm)
I	=	moment of inertia (mm^4)

7. Free Span analysis

Spanning of a pipeline on the seabed causes forces and stresses in the pipe. The criterion for accepting a pipeline configuration is that the pipe should not be subjected to over-stressing, nor to excessive dynamic loading because of resonant oscillations of the pipe caused by the vortex shedding phenomenon during installation, testing and throughout its operating life.

The pipeline span assessment includes the following items:

- Static span analysis
- Dynamic span analysis.

The static analysis concerns the determination of the pipe stresses under functional- and static environmental loads for a given span length.

The dynamic span analysis is based on criteria for prevention of vortex induced vibrations (VIV) as outlined in NEN 3656 considering both current- and wave induced velocities.

In addition, operational limits of the trenching equipment, limits the span gap (distance between the pipe and the seabed).

Although the pipeline will be buried below the seabed prior to its operation, the pipeline must be checked for spanning for the period between installation and burial.

In the analysis, along with the seabed topography, both functional and environmental loads are taken into consideration to check pipeline structural integrity under the considered load cases.

7.1. Static span

Combining hoop, longitudinal and bending stresses in the pipeline, which shall satisfy criteria for equivalent stresses, gives the maximum allowable static span lengths. Checks are to be made for the installation, hydro test and operational load case.

The maximum bending moment is calculated from the (vector) combination of the pipelines' own weight and hydrodynamic forces for the maximum wave condition:

$$q = \sqrt{\gamma_W{}^2 \cdot W_S{}^2 + \gamma_H{}^2 \cdot (F_D + F_I)^2}$$

Where:

γ_W	=	load factor as per Table 5-3 (-)
γ_H	=	load factor as per Table 5-3 (-)

End fixity of an actual span is commonly assumed between fixed - fixed and fixed – pinned and the bending moment (M) calculated from:

$$M = \frac{q \cdot L^2}{10}$$

Where:

L	=	Maximum allowable span length [m]

The maximum allowable bending moment (M_{all}) is given by:

$$M_{all} = \frac{2 \cdot I \cdot \sigma_b}{OD}$$

Where:

I	=	moment of inertia (m^4)
OD	=	pipeline outside diameter (m)
Sb	=	maximum allowable bending stress

The maximum allowable static span can then be determined by:

$$L\max = \sqrt{\frac{20 \cdot \sigma_b \cdot I}{OD \cdot q}}$$

The maximum allowable span length follows from the condition that the equivalent stress (S_e) from the load combination satisfies the following conditions:

For the operational and hydrotest cases: $S_e \leq 0.85 \times (R_e + R_{ev}) / \gamma_m$

For the installation case: $S_e \leq R_e / \gamma_m$

Where:

R_e = minimum yield stress at 20 °C (N/mm^2)

R_{ev} = minimum yield stress at design temperature (N/mm^2)

γ_m = material factor (-) => 1.1

7.1.1. Load cases

The maximum static span will be determined for the load cases, and considering the environmental load return periods, as detailed in Table 7-1:

Condition	Wave Height Return Period	Current velocity Return Period
Installation	$H_{max,1yr}$	1 yr
Hydrotest	$H_{max,1yr}$	1 yr
Operational,1	$H_{max,100yr}$	10 yr
Operational,2	$H_{max,10yr}$	100 yr

Table 7-1 Load Cases for Span Assessment

7.2. Dynamic span

Flow of water particles induced by currents and waves perpendicular to a spanning pipeline or riser span can lead to vortices being shed. This will disrupt the flow around the pipe and thereby potentially cause periodic loads on the pipeline or riser, also known as Vortex Induced Vibration (VIV).

The natural frequency of a span being close to the vortex shedding frequency can result in a resonant oscillation, possibly resulting in fatigue failure of the pipeline or riser.

The oscillations of the span may occur in two directions:

- in line with the flow (parallel to the flow direction of the water particles)
- in cross flow direction (perpendicular to the flow direction of the water particles)

When assessing VIV, the span should be confirmed to be within acceptable limits set by either avoidance of VIV or an acceptable fatigue life for both the installation and operational condition.

Relevant dimensionless parameters governing the VIV phenomenon are the reduced velocity (V_r) and stability parameter (K_s).

The reduced velocity (V_r) parameter is defined by:

$$V_r = \frac{V_s}{f_{n \cdot OD_{tot}}}$$

Where,

V_s	=	water particle velocity due to current and significant wave (m/s)
f_n	=	1st natural frequency of the pipe span (1/s)
OD_{tot}		total outside diameter of the pipe (m)

The 1st natural frequency can be calculated from:

$$f_n = \frac{a}{2\pi} \cdot \sqrt{\frac{E \cdot I}{m_e \cdot L^4}}$$

Where,

a	=	frequency factor (-) => 15.4 for a fixed-pinned beam, which is used for the pipe
E	=	Young's modulus (N/m^2)
I	=	moment of inertia (m^4)
L	=	length of span in pipeline / riser (m)

The effect of the CWC on the moment of inertia and the Young's modulus is not taken into account; this is a conservative approximation. The outer diameter is including the CWC.

The stability parameter (K_s) is defined by:

$$K_s = \frac{2 \cdot m_e \cdot \delta}{\rho_{sw} \cdot OD_{tot}^2}$$

Where,

m_e	=	effective mass of pipe (kg/m)
ρ_{sw}	=	density seawater (kg/m^3)
δ	=	logarithmic decrement of damping (-) => δ = 0.126 for steel

The effective mass of the pipe can be calculated as:

$$m_e = m + {}^{\pi}\!/_{4} \cdot C_M \cdot \rho_{sw} \cdot OD_{tot}{}^2$$

Where,

m	=	Pipeline / riser mass (kg/m)
Cm	=	added mass coefficient (-)

NEN 3656 states that In-line oscillations will occur if $K_s \leq 1.8$ and cross flow oscillations will occur if $K_s \leq 16$.

7.2.1. In-line VIV

NEN 3656 furthermore states that in-line oscillations of the span occur if the reduced velocity is within the range of: $1.0 \leq Vr \leq 3.5$

Vortices around a spanning pipe occur in a relatively steady state environment. The wave induced velocity varies from a maximum at t=0, to zero at t=1/4*Twave. Furthermore, the system does not respond instantaneously to the applied forcing. To ignore the wave induced velocity in assessing the allowable dynamic span length would be too optimistic, to account for the maximum induced value would be too conservative, therefore reference is made to DNV-RP-F105. “Free Spanning Pipelines.” (ref. [3]).

According to Ref. [3], fatigue damage due to in-line VIV can be neglected if the current flow velocity ratio α, as defined by the equation below is smaller than 0.8.

$$\alpha = \frac{v_{cur}}{v_{cur} + v_{wave}}$$

Where,

v_{cur}	=	Particle velocity due to current [m/s]
v_{wave}	=	Particle velocity due to waves [m/s]

7.2.2. Cross-flow VIV

The occurrence of cross flow oscillations depends on the magnitude of the Reynolds number, Re, and the reduced velocity as given in Figure 7-1.

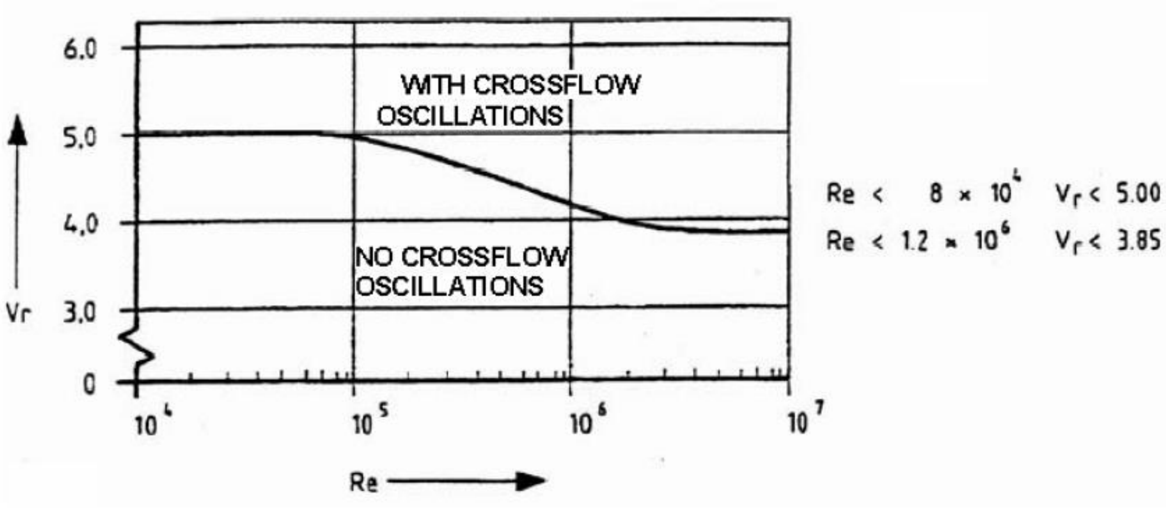


Figure 7-1 Reduced velocity for cross flow oscillations

$$\mathrm{Re} = \frac{\mathrm{v} \cdot OD_{tot}}{\nu}$$

Where,

v	=	particle velocity (m/s)
OD_{tot}	=	pipeline outside diameter (m)
n	=	Kinematic viscosity water (m^2/s) => 1,307 x 10^{-6} (at 10 °C)

8. Bottom roughness

8.1. General

To ensure the structural integrity of the pipeline over its entire design life finite element analyses will be carried out using industry proven software like Ansys or RFEM.

The analysis will assess the interaction between the pipeline and the supporting soil along the entire pipeline route and will be carried out in accordance with the requirements of NEN 3656 (Ref. [1]). The analysis will determine the number of spans exceeding the allowable span length and the subsequent pre-sweeping requirements. The design loads at the tie-in locations will be determined and in addition the analysis will assess the upheaval buckling response of the pipeline system under operating conditions.

The analysis will account for the load history of the pipelines over the design life by considering the following load cases:

- Installation (empty);
- Installation (flooded);
- Pipeline operation - nominal (nominal wall thickness content filling maximum operating pressure and temperature);
- Pipeline operation - corroded (corroded wall thickness content filling maximum operating pressure and temperature).

The pipeline will be modelled by uniaxial elements with tension-compression torsion and bending capabilities and can account for internal pressure effects. The element is a 3D element with six degrees of freedom translations in the x y and z directions and rotations about the x y and z axes. In addition the element needs to account for buoyancy wave and current loads and to be capable of large deflections and rotations.

The pipeline is to be modelled with a maximum element length of 0.5 – 1.0 m and accounts for all curvatures in the horizontal plane and undulations in the vertical plane. Pipe-soil interaction is simulated using three independent non-linear spring elements attached to each pipe element. The springs represent the soil frictional resistance in the axial and lateral directions and the soils bearing capacity in the vertical direction.

For sections of the pipeline which are buried additional vertical non-linear springs representing the uplift resistance of the trench backfill material will be attached to the pipe elements.

Seabed roughness will be simulated by displacing the vertical springs representing the soil bearing capacity to the correct depth based on the bathymetric data and allowing the pipe to move and rest on the vertical springs.

When the depth of the pipeline at a certain point is less than the depth of the seabed a "free span" is identified. Similar succeeding joints indicate a larger span. The length of the free span is determined by subtracting the coordinates of the beginning of the span from the coordinates of the span end.

At pipeline termination points an additional axial spring will be attached to the pipeline ends to incorporate the structural response of the subsea tie-in spool/riser and supporting piping.

8.2. Pipe-soil interaction

The characteristics of the springs which simulate the pipe-soil interaction are defined through non-linear force deflection curves. These force-deflection curves describe the frictional restraint provided by the soil to the pipeline in the axial lateral direction and the soils bearing capacity /upwards resistance in the vertical direction.

2 situations can be distinguished:

- exposed pipeline
  - axial soil resistance;
  - lateral soil resistance;
  - vertical bearing capacity (downward resistance);

- buried pipeline
  - axial soil resistance;
  - lateral soil resistance;
  - vertical bearing capacity (downward resistance);
  - vertical upward soil resistance;

Table 8-1 gives an overview of the calculation basis of the mentioned soil resistances/capacities.

Direction	Exposed pipeline	Buried pipeline
Axial	Function of pipe submerged weight and axial Coulomb friction coefficient	Function of pipe diameter, burial depth and effective unit soil weight.
Lateral	Combination of Coulomb friction part and passive soil resistance due to build-up of soil penetration (ref. [5])	Based on horizontal bearing capacity factor (ref. [9])
Vertical bearing	Based on bearing capacity formulas for ideal 2-D strip foundations ref. [3]	Based on bearing capacity formulas for ideal 2-D strip foundations ref. [3]
Vertical upward	N/A	As per ref. [6] based on burial depth pipe diameter and submerged soil weight

Table 8-1 Overview soil resistance/capacity calculation basis

9. Upheaval Buckling

Buried pipelines exposed to compressive effective axial forces may get unstable beyond its anchor point and move vertically out of the seabed if the cover has insufficient resistance. An out-of-straightness configuration will result in forces acting on the cover perpendicular to the pipeline. In case these vertical forces exceed the cover resistance the pipeline will buckle upwards.

The relation between minimum required cover height and the imperfection height (out-of-straightness) will be established in accordance with ref. [11].

Parameters used in the assessment of upheaval buckling are the dimensionless imperfection length parameter (Φ_L):

$$\Phi_L = L \cdot \sqrt{\frac{N_e}{EI}}$$

Where:

L	=	exposure length (m)
N_e	=	effective axial compressive force (N)
EI	=	bending stiffness (N m^2)

And the dimensionless maximum download parameter (Φ_w):

$$\Phi_w = \frac{w \cdot E \cdot I}{\Delta_{calc} \cdot N_e^{\,2}}$$

Where:

w	=	required download [N/m]
Δ_{calc}	=	imperfection height [m]

Depending on the Φ_L value the required download is derived from Φ_w in accordance with:

$$\Phi_w = 0.0646 \quad \text{for} \quad \Phi_L < 4.49$$

$$\Phi_w = \frac{5.68}{\phi_L^{\,2}} - \frac{88.35}{\phi_L^{\,4}} \quad \text{for} \quad 4.49 < \Phi_L < 8.06$$

$$\Phi_w = \frac{9.6}{\phi_L^{\,2}} - \frac{343}{\phi_L^{\,4}} \quad \text{for} \quad \Phi_L > 8.06$$

In cohesionless soils the uplift resistance (q) due to the cover of the pipe can be calculated from:

$$q = \gamma \cdot H \cdot OD \cdot \left(1 + f \cdot \frac{H}{OD}\right)$$

Where:

γ	=	effective under water weight of soil (N/m^3)
H	=	depth of cover (m)
OD	=	outside diameter of pipe (m)
f	=	uplift coefficient 0.5 for dense material 0.1 for loose material

The calculated required download (w) shall be smaller than the actual combination of the submerged weight and uplift resistance of the pipeline.

The simplified method from Reference [11] is conservative in that it does not model a number of mitigating factors such as:

- The finite axial stiffness of the pipeline which determines how rapidly the axial force diminishes as the pipeline moves upwards
- The pipeline resistance to axial movement through the soil determines how far the pipeline can slide towards a developing buckle.

Both the above factors may cause progressive upheaval buckling predicted by the analysis method in Reference [11] not to occur.

Further the sinusoidal imperfection profile assumed in the model is envisaged to yield conservative download requirements.

The results will be presented as a maximum imperfection length with respect to the cover depth and the imperfection height.

10. Cathodic Protection

As per NEN 3656 the cathodic protection system of the pipeline bundle will be designed as per ref. [12]. The characteristics of a typical anode element are given in Table 10-1.

Item	Value
Type	Half Shell Bracelet
Material	Aluminium
Cable connections	2 x @ 20" pipeline

Table 10-1 Typical anode characteristics

The cathodic protection will be designed to prevent external corrosion of the pipeline. The mass and spacing of the anodes will be such that the following criteria are met:

- Total anode mass to meet the mean and final current demand over the design life of the pipeline.
- Anode current output to meet the required current output at the end of the design life.
- Anode separation not to exceed a value of 300 m.

The pipeline will be divided in to sections where changes in conditions, such as water depth, operating temperature or burial, can give rise to variations in design current density.

From the pipeline dimensions and the coating selected, the mean current demand, I_{cm}, and the final demand, I_{cf}, shall be calculated separately as per the following:

$$I_c = A_c \cdot f_c \cdot i_c$$

Where:

I_c = the current demand for a specific pipeline section calculated for mean and final conditions (A)

A_c = the total surface area for a specific pipeline section (m^2)

f_c = the coating breakdown factor determined for mean and final conditions (-)

i_c = the current density selected for mean and final conditions (A/m^2)

For pipelines fully buried, a design current density (mean and final) of 20 mA/m^2 should be used irrespective of seawater temperature, oxygen content or depth as per Section 7.4.3 of Ref. [12].

The coating breakdown factors for mean and final conditions, f_c, taking into consideration the deign life of the pipeline, are calculated as follows.

The mean coating breakdown factor, $\overline{f_c}$, is determined by:

$$\overline{f_c} = f_i + (0.5\Delta f \cdot t_{dl})$$

And the mean coating breakdown factor, f_f , is determined by

$$f_f = f_i + (\Delta f \cdot t_{dl})$$

Where:

f_i = the initial coating breakdown factor at the start of pipeline operation (-)

Δf = the average yearly increase in the coating breakdown factor (-)

t_{dl} = the design life (yrs)

The initial coating breakdown factor and average yearly increase in breakdown factor are dependent on the anti-corrosion coating and field joint coating material. Values for various coating are taken from [12] and reported in Table 9-2.

Factory-applied coating type	Field joint coating type	f_i	Δf
Fusion-bonded epoxy (FBE)	Heat-shrinkable sleeves (HSS[a])	0,080	0,003 5
	FBE	0,060	0,003 0
Three-layer coating systems including epoxy, adhesive and polyethylene (3LPE)	HSS[a]	0,009	0,000 6
	FBE	0,008	0,005
	Multilayer coating including epoxy and PE (e.g. moulded, HSS[a] or flame spray)	0,007	0,000 5
Three-layer coating systems including epoxy, adhesive and polypropylene (3LPP)	HSS[a]	0,007	0,000 3
	FBE	0,006	0,000 2
	Multilayer coating including epoxy and PP (e.g. HSS[a], hot tapes, moulding or flame spray)	0,005	0,000 2
Heat insulation multilayer coating systems including epoxy, adhesive and/or PE, PP or PU	Thick multilayer coating systems including epoxy, adhesive and/or PE, PP, PU, HSS[a] or a combination of these products.	0,002	0,000 1
Thick coatings: elastomeric materials (e.g. polychloroprene or EPDM) or glassfibre-reinforced resins	Thick elastomeric materials or glassfibre-reinforced resins	0,002	0,000 1
Flexible pipelines	Not applicable (mechanical couplings)	0,002	0,000 1

[a] HSS can be used with or without primer.

Table 10-2 Coating breakdown factors [12]

Having established the mean current demand, the total required mass of anode material for a specific pipeline section is determined as follows:

$$m = I_{cm} \cdot t_{dl} \cdot \frac{8760}{\mu \cdot \varepsilon}$$

Where:

m = the total net anode mass, for the specific pipeline section (kg)

I_{cm} = the mean current demand for the specific pipeline section (A)

μ = is the utilization factor (-) = 0.8 for bracelet anodes as per Section 8.4 of Ref. [12].

ε = the electrochemical capacity of the anode material per kilogram (A/h)

The electrochemical capacity of the anode material is dependent on the surface temperature of the anode and its burial status. The applicable values are taken from Section 8.3 of Ref. [12] and reported in Table 9-3.

Having determined the total net anode mass required to meet the current demand, the minimum number of anodes required in a specific pipeline section, will be determined as follows:

$$n = \frac{m}{m_a}$$

Where:

n = the number of anodes to be installed on the specific pipeline section (-)

m_a = the individual net anode mass (kg)

The minimum number of anodes, n, shall be determined considering the maximum allowable anode spacing of 300m as reported in Section 8.1 of Ref. [12].

Anode type	Anode surface temperature[a]	Immersed in seawater		Buried in seawater sediments[d]	
		Potential	Electrochemical capacity	Potential	Electrochemical capacity
		Ag/AgCl/ seawater	ε	Ag/AgCl/ seawater	ε
	°C	mV	A·h/kg	mV	A·h/kg
Aluminium	< 30	− 1 050	2 000	− 1 000	1 500
	60	− 1 050	1 500	− 1 000	800
	80[b]	− 1 000	900	− 1 000	400
Zinc	< 30	− 1 030	780	− 980	750
	> 30 to 50[c]			− 980	580

Electrochemical capacity for a given alloy is a function of temperature and anode current density. Reference is made to Annex A for guidance on CP design for variations in anode current densities.

For non-buried pipelines, the anode surface temperature should be taken as the external pipeline temperature and not the internal fluid temperature. For buried pipelines, the anode surface temperature shall be taken as the internal fluid temperature.

[a] For anode surface temperatures between the limits stated, the electrochemical capacity shall be interpolated.

[b] For aluminium anodes, the anode surface temperature shall not exceed 80 °C unless the performance has been demonstrated in tests and has been documented.

[c] For zinc anodes, the anode surface temperature shall not exceed 50 °C unless satisfactory performance has been demonstrated in tests and has been documented.

[d] Pipelines which are rock-dumped shall be considered as buried in seawater sediments.

Table 10-3 Design values for galvanic anodes [12]

To provide the required current, the actual anode current output shall be greater than or equal to the required current output:

$$I_{af} \geq I_f$$

Where:

I_{af} = the actual end-of-life individual current output (A)

I_f = the required end-of-life individual anode current output (A)

The required end-of-life individual anode current output, I_f, shall be calculated from the following:

$$I_f = \frac{I_{cf}}{n}$$

Where:

I_{cf} = the total current demand for the protection of the specific pipeline section at the end of life (A)

For a given anode size and mass, the actual individual anode current output at the end of life, I_{af}, is calculated from the below equation:

$$I_{af} = \frac{E_c - E_a}{R_a}$$

Where:

E_c = the design protection potential (V)

E_a = the design closed-circuit potential of the anode (V)

R_a = the total circuit resistance, which is assumed to be equivalent to the anode resistance (ohms)

The anode resistance, R_a, shall be calculated as follows:

$$R_a = 0.315 \frac{\rho}{\sqrt{A}}$$

Where:

ρ = the environmental resistivity (ohm.m)

A = the exposed surface area of the anode (m^2)

For determining the end-of-design-life anode-to-seawater resistance, the anodes shall be assumed to be consumed to an extent given by their utilization factor. The approximate anode dimensions (exposed surface area) corresponding to this degree of wastage shall be used in the anode resistance formula for R_a.

A. Environmental Data GEOxyz

Magnetic Contacts

MAG ID	Easting	Northing	Size nT
MAG_001	717953,7	5940271,5	1846
MAG_002	717991,0	5940276,5	2449
MAG_003	718039,9	5940290,0	1412
MAG_004	718041,2	5940299,0	88
MAG_005	718096,4	5940310,5	5750
MAG_006	718148,3	5942788,5	35
MAG_007	718149,5	5940331,0	2207
MAG_008	718198,9	5940350,5	4606
MAG_009	718247,8	5940365,0	878
MAG_010	718312,4	5940395,0	4218
MAG_011	718346,7	5940412,0	1847
MAG_012	718409,7	5940429,5	1254
MAG_013	718424,0	5944905,0	44
MAG_014	718444,3	5942692,5	828
MAG_015	718462,9	5941110,5	163
MAG_016	718472,4	5940453,5	1966
MAG_017	718484,8	5942724,5	4590
MAG_018	718491,8	5940449,0	962
MAG_019	718506,9	5942723,0	1900
MAG_020	718508,2	5942754,0	9330
MAG_021	718509,3	5940455,5	558
MAG_022	718516,3	5942748,5	5361
MAG_023	718534,0	5942694,0	1157
MAG_024	718548,1	5945123,5	32

MAG_025	718565,1	5940481,0	3279
MAG_026	718595,9	5942616,0	52
MAG_027	718617,5	5940493,0	5243
MAG_028	718662,3	5940506,0	613
MAG_029	718720,1	5940516,0	2386
MAG_030	718766,9	5940523,0	2963
MAG_031	718829,4	5940541,0	706
MAG_032	718856,6	5940558,0	9291
MAG_033	718875,8	5944329,5	23
MAG_034	718975,9	5941798,0	86
MAG_035	718995,8	5942736,5	67
MAG_036	719033,8	5946829,5	22
MAG_037	719274,9	5946749,5	136
MAG_038	719349,1	5948063,0	51
MAG_039	719395,2	5946438,0	14
MAG_040	719449,5	5948089,0	11
MAG_041	719489,0	5947981,0	40
MAG_042	719645,7	5947744,5	73
MAG_043	720080,7	5949053,0	11
MAG_044	720398,8	5952407,0	22
MAG_045	720432,3	5952500,5	428
MAG_046	720451,3	5952357,0	15
MAG_047	720452,1	5952553,0	197
MAG_048	720492,5	5952478,5	6757
MAG_049	720507,6	5952530,5	846
MAG_050	720589,2	5952492,5	539
MAG_051	720687,5	5951846,0	11
MAG_052	720733,6	5952469,5	17

MAG_053	720796,44	5954306,50	11
MAG_054	720823,9	5952486,5	38
MAG_055	720895,0	5952512,5	195
MAG_056	720896,6	5952528,5	258
MAG_057	720966,9	5952512,5	155
MAG_058	720972,6	5952521,0	30
MAG_059	720981,25	5955029,50	15
MAG_060	721006,69	5954892,50	18
MAG_061	721006,69	5954892,5	18
MAG_062	721043,6	5954396,5	50
MAG_063	721043,63	5954396,50	50
MAG_064	721043,6	5954396,5	50
MAG_065	721050,88	5954393,50	66
MAG_066	721050,9	5954393,5	66
MAG_067	721050,9	5954393,5	66
MAG_068	721097,9	5953584,0	8
MAG_069	721144,6	5952537,5	59
MAG_070	721224,2	5952542,0	88
MAG_071	721272	5954784,5	23
MAG_072	721272,00	5954784,50	23
MAG_073	721272,0	5954784,5	23
MAG_074	721395,3	5952547,0	97
MAG_075	721424,3	5952569,5	110
MAG_076	721424,88	5954616,50	285
MAG_077	721424,9	5954616,5	285
MAG_078	721424,88	5954616,5	285
MAG_079	721424,9	5954616,5	285
MAG_080	721430,5	5952680,5	22

MAG_081	721567,25	5954416,50	12
MAG_082	721567,3	5954416,5	12
MAG_083	721567,25	5954416,5	12
MAG_084	721567,3	5954416,5	12
MAG_085	721568,5	5954404,5	22
MAG_086	721568,50	5954404,50	22
MAG_087	721571,7	5954762,5	18
MAG_088	721571,69	5954762,50	18
MAG_089	721571,69	5954762,5	18
MAG_090	721571,7	5954762,5	18
MAG_091	721615,3	5954915,0	27
MAG_092	721615,25	5954915,00	27
MAG_093	721615,25	5954915	27
MAG_094	721615,3	5954915	27
MAG_095	721625,25	5954596,50	53
MAG_096	721625,3	5954596,5	53
MAG_097	721625,25	5954596,5	53
MAG_098	721625,3	5954596,5	53
MAG_099	721625,4	5954919,0	28
MAG_100	721625,38	5954919,00	28
MAG_101	721625,38	5954919	28
MAG_102	721625,4	5954919	28
MAG_103	721645,7	5954971,5	66
MAG_104	721645,69	5954971,50	66
MAG_105	721645,69	5954971,5	66
MAG_106	721645,7	5954971,5	66
MAG_107	721650,5	5954550	376
MAG_108	721650,50	5954550,00	376

MAG_109	721650,5	5954550,0	376
MAG_110	721657,8	5954589	358
MAG_111	721657,8	5954589,0	358
MAG_112	721657,81	5954589,00	358
MAG_113	721657,81	5954589	358
MAG_114	721658,0	5954624,0	45
MAG_115	721658,00	5954624,00	45
MAG_116	721658	5954624	45
MAG_117	721666,7	5954576,0	1100
MAG_118	721666,69	5954576,00	1100
MAG_119	721666,69	5954576	1100
MAG_120	721666,7	5954576	1100
MAG_121	721670,5	5954647,5	27
MAG_122	721670,50	5954647,50	27
MAG_123	721672,2	5954562,0	2733
MAG_124	721672,19	5954562,00	2733
MAG_125	721672,19	5954562	2733
MAG_126	721672,2	5954562	2733
MAG_127	721683,56	5954529,00	252
MAG_128	721683,6	5954529,0	252
MAG_129	721683,56	5954529	252
MAG_130	721683,6	5954529	252
MAG_131	721685,69	5954453,00	110
MAG_132	721685,7	5954453,0	110
MAG_133	721685,69	5954453	110
MAG_134	721685,7	5954453	110
MAG_135	721691,2	5954590,0	360
MAG_136	721691,19	5954590,00	360

MAG_137	721691,19	5954590	360
MAG_138	721691,2	5954590	360
MAG_139	721695,69	5954426,00	35
MAG_140	721695,7	5954426,0	35
MAG_141	721695,69	5954426	35
MAG_142	721695,7	5954426	35
MAG_143	721702,2	5954504,0	58
MAG_144	721702,19	5954504,00	58
MAG_145	721702,19	5954504	58
MAG_146	721702,2	5954504	58
MAG_147	721708,19	5954468,00	119
MAG_148	721708,2	5954468,0	119
MAG_149	721708,19	5954468	119
MAG_150	721708,2	5954468	119
MAG_151	721709,3	5954964,0	21
MAG_152	721709,25	5954964,00	21
MAG_153	721709,25	5954964	21
MAG_154	721709,3	5954964	21
MAG_155	721806,3	5954401,5	10
MAG_156	721806,3	5954401,5	10
MAG_157	721806,31	5954401,50	10
MAG_158	721806,31	5954401,5	10
MAG_159	722858,06	5954425,00	43
MAG_160	722858,1	5954425,0	43
MAG_161	722858,1	5954425	43
MAG_162	723840,1	5954855,5	31
MAG_163	723840,13	5954855,50	31
MAG_164	723843,06	5954772,50	17

MAG_165	723843,1	5954772,5	17
MAG_166	723868,19	5954698,50	23
MAG_167	723868,2	5954698,5	23
MAG_168	723879,8	5954617	25
MAG_169	723879,81	5954617,00	25
MAG_170	723905,06	5954389,00	15
MAG_171	723905,1	5954389,0	15
MAG_172	723905,1	5954389	15
MAG_173	723911,8	5954159	16
MAG_174	723911,81	5954159,00	16
MAG_175	723927,25	5954010,00	14
MAG_176	723927,3	5954010	14
MAG_177	723945,06	5953933,50	16
MAG_178	723945,1	5953933,5	16
MAG_179	724080,88	5954522,00	40
MAG_180	724080,9	5954522,0	40
MAG_181	724080,9	5954522	40
MAG_182	724147,19	5954742,00	61
MAG_183	724147,2	5954742	61
MAG_184	724181,8	5954587,5	57
MAG_185	724181,81	5954587,50	57
MAG_186	724182,56	5954368,00	43
MAG_187	724182,6	5954368,0	43
MAG_188	724182,6	5954368	43
MAG_189	724191,56	5954659,00	54
MAG_190	724191,6	5954659	54
MAG_191	724205	5954508,5	31
MAG_192	724205,00	5954508,50	31

MAG_193	724205,0	5954508,5	31
MAG_194	724223,6	5954348,5	27
MAG_195	724223,63	5954348,50	27
MAG_196	724223,6	5954348,5	27
MAG_197	724298,25	5954723,50	41
MAG_198	724298,3	5954723,5	41
MAG_199	724410,1	5954332	36
MAG_200	724410,13	5954332,00	36
MAG_201	724410,1	5954332,0	36
MAG_202	724420,9	5954339	38
MAG_203	724420,94	5954339,00	38
MAG_204	724420,9	5954339,0	38
MAG_205	724426,56	5954103,00	27
MAG_206	724426,6	5954103	27
MAG_207	724436,6	5954034	31
MAG_208	724436,63	5954034,00	31
MAG_209	724442,19	5954251,00	18
MAG_210	724442,2	5954251,0	18
MAG_211	724442,2	5954251	18
MAG_212	724449,06	5954180,50	16
MAG_213	724449,1	5954180,5	16
MAG_214	724449,1	5954180,5	16
MAG_215	724509,3	5953941,5	48
MAG_216	724509,31	5953941,50	48
MAG_217	724512,88	5954320,50	12
MAG_218	724512,9	5954320,5	12
MAG_219	724512,9	5954320,5	12
MAG_220	724611,8	5953854,5	26

MAG_221	724611,81	5953854,50	26
MAG_222	724706,25	5953751,50	26
MAG_223	724747,06	5953610,50	37
MAG_224	724772,75	5953676,00	29
MAG_225	725618,75	5953886,50	38
MAG_226	725618,8	5953886,5	38
MAG_227	726342,9	5953654	25
MAG_228	726342,94	5953654,00	25
MAG_229	727182,38	5954201,00	25
MAG_230	727182,4	5954201,0	25
MAG_231	727182,4	5954201	25
MAG_232	727518,9	5953952	5
MAG_233	727518,94	5953952,00	5
MAG_234	728994,88	5954791,50	14
MAG_235	728994,9	5954791,5	14
MAG_236	728994,9	5954791,5	14
MAG_237	729047,19	5955011,50	14
MAG_238	729047,2	5955011,5	14
MAG_239	729615,69	5955031,50	26
MAG_240	729615,7	5955031,5	26
MAG_241	729615,7	5955031,5	26

Side Sonar Scan Contacts

Contact ID	Easting	Northing	Height	Contact Type
DEB_001	718843,3	5945900,7	5.9x1.5x0.1	Debris
DEB_002	718696,2	5943976,4	3.0x0.3x0.1	Debris
DEB_003	718510,6	5942751,2	1.5x1.7xnmh	Debris
DEB_004	718689,5	5942724,0	3.0x0.5x0.3	Debris

DEB_005	718419,5	5942669,9	0.8x0.3x0.1	Debris
DEB_006	718479,3	5942653,2	2.5x1.2x0.1	Debris
DEB_007	718581,4	5942595,0	5.0x1.3x0.3	Debris
DEB_008	718582,9	5942591,3	4.1x1.0x0.6	Debris
DEB_009	718580,4	5942585,2	1.8x0.5x0.2	Debris
DEB_010	718589,2	5942584,2	5.1x2.4x0.3	Debris
DEB_011	718584,4	5942581,4	4.1x3.3x0.5	Debris
DEB_012	718550,1	5942539,3	1.4x0.8x0.2	Debris
DEB_013	718606,0	5942526,9	2.9x1.0x0.6	Debris
DEB_014	718630,6	5942524,1	2.0x0.5x0.1	Debris
DEB_015	720403,1	5952036,9	1.9x0.7x0.2	Wreck
DEB_016	718395,4	5945567,7	1.0x0.7x0.1	Wreck
DEB_017	718387,7	5945566,4	3.9x0.5x0.1	Debris
DEB_018	718282,9	5944250,1	1.6x0.7x0.3	Debris
DEB_019	718930,1	5944019,3	6.2x1.8x0.4	Debris
DEB_020	718995,4	5943832,0	2.0x0.6x0.2	Debris
DEB_021	718878,1	5943526,3	2.1x0.7x0.2	Debris
DEB_022	718167,1	5942830,6	2.2x0.8x0.2	Debris
DEB_023	718254,5	5942712,2	2.9x1.1x0.1	Debris
DEB_024	718142,1	5942390,0	3.4x1.6x0.8	Debris
DEB_025	718784,2	5941352,3	3.3x1.5xnmh	Debris
DEB_026	718687,6	5941281,5	1.4x0.6x0.1	Debris
SSS_001	720764,04	5955368,29	0,9	Debris
SSS_002	720829,13	5954453,20	0,6	Debris
SSS_003	720820,73	5954342,72	0,6	Object
SSS_004	720821,77	5954270,88	0,5	Object
SSS_005	720880,99	5954431,59	0,6	Object
SSS_006	720892,17	5954300,94	0,8	Object

SSS_007	720893,26	5954290,00	0,7	Object
SSS_008	720905,80	5954298,46	0,9	Object
SSS_009	720945,81	5954410,62	0,6	Object
SSS_010	720952,19	5954327,47	0,6	Object
SSS_011	720959,37	5954364,43	0,6	Object
SSS_012	720960,29	5954352,58	0,7	Object
SSS_013	720968,48	5954364,83	0,6	Object
SSS_014	720988,35	5954348,47	1	Object
SSS_015	720987,94	5954062,19	0,9	Object
SSS_016	721039,97	5954486,91	0,6	Object
SSS_017	720995,11	5954033,91	0,8	Object
SSS_018	721014,90	5954205,53	0,5	Object
SSS_019	721048,07	5954440,97	0,5	Object
SSS_020	721014,60	5954144,86	0,6	Object
SSS_021	721047,79	5954403,65	0,8	Object
SSS_022	721023,57	5954124,07	0,8	Object
SSS_023	721031,84	5954112,67	0,6	Object
SSS_024	721055,06	5954273,47	0,5	Object
SSS_025	721070,04	5954387,96	0,5	Object
SSS_026	721047,65	5954157,24	0,8	Object
SSS_027	721039,23	5954011,52	0,5	Object
SSS_028	721083,56	5954252,55	0,6	Object
SSS_029	721077,94	5954055,23	0,5	Object
SSS_030	721120,45	5954342,55	0,6	Object
SSS_031	721082,86	5953986,73	0,5	Object
SSS_032	721096,70	5954103,85	0,6	Object
SSS_033	721124,20	5954225,46	0,6	Object
SSS_034	721108,47	5954016,11	1	Object

SSS_035	721111,52	5954015,55	0,6	Object
SSS_036	721154,23	5954387,61	0,5	Object
SSS_037	721200,49	5954647,37	0,6	Object
SSS_038	721129,50	5954019,15	0,7	Object
SSS_039	721147,68	5954077,59	0,5	Object
SSS_040	721189,65	5954331,95	0,8	Object
SSS_041	721166,42	5954080,67	0,7	Object
SSS_042	721183,36	5954184,19	0,5	Object
SSS_043	721204,09	5954287,89	0,7	Object
SSS_044	721200,07	5954168,32	0,5	Object
SSS_045	721202,45	5954182,88	0,6	Object
SSS_046	721195,78	5953987,53	0,5	Object
SSS_047	721381,17	5955392,95	1,1	Object
SSS_048	721235,00	5954040,36	0,6	Object
SSS_049	721304,21	5954594,42	1	Object
SSS_050	721246,88	5953990,00	0,7	Object
SSS_051	721321,53	5954595,76	0,9	Object
SSS_052	721290,57	5954297,19	0,6	Object
SSS_053	721343,86	5954472,53	0,5	Object
SSS_054	721373,40	5954458,69	0,5	Object
SSS_055	721419,15	5954712,64	0,7	Object
SSS_056	721408,52	5954529,08	1,3	Object
SSS_057	721395,63	5954262,43	0,6	Object
SSS_058	721395,15	5954252,77	0,7	Object
SSS_059	721458,06	5954747,89	0,9	Object
SSS_060	721444,60	5954037,80	0,6	Object
SSS_061	721455,66	5954048,13	0,5	Object
SSS_062	721554,96	5954666,23	0,8	Object

SSS_063	721517,58	5954248,05	0,6	Object
SSS_064	721523,03	5954218,83	0,7	Object
SSS_065	721637,89	5954907,07	0,7	Object
SSS_066	721648,13	5954914,13	0,5	Object
SSS_067	721571,49	5954203,12	0,5	Object
SSS_068	721656,39	5954932,11	1	Object
SSS_069	721616,00	5954554,46	0,6	Object
SSS_070	721674,18	5955016,59	0,5	Object
SSS_071	721655,25	5954793,46	0,7	Object
SSS_072	721625,01	5954519,17	0,7	Object
SSS_073	721680,77	5955011,05	0,7	Object
SSS_074	721652,06	5954564,38	0,6	Object
SSS_075	721604,57	5954084,46	0,7	Object
SSS_076	721626,38	5954092,91	0,5	Object
SSS_077	721625,38	5954063,72	0,7	Object
SSS_078	721717,09	5954862,86	0,6	Object
SSS_079	721718,05	5954870,34	0,7	Object
SSS_080	721738,42	5955038,28	0,7	Object
SSS_081	721723,22	5954856,19	0,6	Object
SSS_082	721624,62	5953973,00	0,7	Object
SSS_083	721767,69	5955126,00	0,6	Object
SSS_084	721775,98	5955044,12	0,7	Object
SSS_085	721796,01	5955132,17	0,8	Object
SSS_086	721801,77	5955134,43	0,7	Object
SSS_087	721710,89	5954302,92	0,5	Object
SSS_088	721800,27	5955078,78	0,5	Object
SSS_089	721746,76	5954595,75	0,6	Object
SSS_090	721788,65	5954958,66	0,6	Object

SSS_091	721808,34	5955123,30	0,6	Object
SSS_092	721684,49	5953956,43	1,6	Object
SSS_093	721798,86	5954964,39	0,6	Object
SSS_094	721766,62	5954616,90	0,8	Object
SSS_095	721819,68	5955039,44	0,8	Object
SSS_096	721759,40	5954496,67	0,6	Object
SSS_097	721704,59	5954008,27	0,5	Object
SSS_098	721712,63	5954066,90	1	Object
SSS_099	721703,78	5953951,67	0,9	Object
SSS_100	721791,38	5954654,79	0,5	Object
SSS_101	721764,51	5954382,53	0,5	Object
SSS_102	721772,48	5954430,59	0,6	Object
SSS_103	721847,33	5954926,04	0,6	Object
SSS_104	721815,38	5954641,85	0,6	Object
SSS_105	721788,50	5954369,26	0,6	Object
SSS_106	721854,68	5954924,85	0,5	Object
SSS_107	721825,40	5954588,20	0,5	Object
SSS_108	721829,40	5954595,07	0,6	Object
SSS_109	721851,99	5954594,19	0,6	Object
SSS_110	721858,18	5954627,12	0,6	Object
SSS_111	721880,66	5954700,94	0,6	Object
SSS_112	721850,61	5954434,71	0,6	Object
SSS_113	721810,07	5953955,71	0,7	Object
SSS_114	721968,21	5955303,95	0,5	Object
SSS_115	721896,80	5954569,62	0,7	Object
SSS_116	721926,97	5954712,77	0,5	Object
SSS_117	721940,17	5954537,16	0,7	Object
SSS_118	721949,13	5954256,82	0,7	Object

SSS_119	722061,99	5954903,71	0,5	Object
SSS_120	722026,14	5954527,01	0,7	Object
SSS_121	721976,86	5953947,97	0,6	Object
SSS_122	722031,16	5954397,32	0,7	Object
SSS_123	722007,93	5954191,32	0,6	Object
SSS_124	722037,39	5954431,37	0,9	Object
SSS_125	722065,60	5954532,75	0,5	Object
SSS_126	722072,28	5954539,20	0,5	Object
SSS_127	722049,53	5954224,70	0,8	Object
SSS_128	722128,63	5954814,33	0,6	Object
SSS_129	722131,17	5954814,97	0,5	Object
SSS_130	722141,98	5954862,02	0,5	Object
SSS_131	722091,64	5954408,44	0,8	Object
SSS_132	722066,30	5954157,96	0,6	Object
SSS_133	722079,71	5954193,94	0,6	Object
SSS_134	722127,92	5954494,60	0,5	Object
SSS_135	722094,41	5954197,41	0,5	Object
SSS_136	722100,07	5954244,99	0,7	Object
SSS_137	722112,91	5954349,57	1	Object
SSS_138	722112,75	5954276,00	0,7	Object
SSS_139	722119,71	5954332,11	0,6	Object
SSS_140	722168,47	5954646,15	0,5	Object
SSS_141	722175,02	5954701,14	0,7	Object
SSS_142	722117,03	5954180,65	0,5	Object
SSS_143	722162,02	5954289,85	0,6	Object
SSS_144	722256,41	5954766,99	0,8	Object
SSS_145	722258,54	5954554,99	0,6	Object
SSS_146	722266,05	5954620,89	0,5	Object

SSS_147	722266,66	5954547,24	0,6	Object
SSS_148	722348,34	5955174,34	1	Object
SSS_149	722271,90	5954311,52	0,5	Object
SSS_150	722326,41	5954704,99	1,1	Object
SSS_151	722299,30	5954139,59	1	Object
SSS_152	722362,88	5954613,53	0,6	Object
SSS_153	722407,24	5954745,37	0,6	Object
SSS_154	722397,54	5954086,30	0,6	Object
SSS_155	722524,39	5954965,64	0,7	Object
SSS_156	722504,06	5954768,70	0,5	Object
SSS_157	722557,20	5954951,23	0,6	Object
SSS_158	722475,09	5954215,99	0,6	Object
SSS_159	722536,86	5954258,29	0,7	Object
SSS_160	722583,42	5954193,39	0,5	Object
SSS_161	722664,75	5954088,19	0,5	Object
SSS_162	722698,08	5954168,32	0,7	Object
SSS_163	722990,18	5955000,42	0,6	Object
SSS_164	723059,38	5954145,40	0,6	Object
SSS_165	723228,22	5954951,32	0,8	Object
SSS_166	723230,39	5954954,08	0,6	Object
SSS_167	723246,39	5954499,21	0,8	Object
SSS_168	723264,94	5954042,88	0,6	Object
SSS_169	723277,68	5953991,55	0,8	Object
SSS_170	723288,81	5953947,23	0,5	Object
SSS_171	723312,59	5954027,25	0,5	Object
SSS_172	723325,45	5954026,92	0,6	Object
SSS_173	723346,77	5954092,76	0,5	Object
SSS_174	723383,38	5954065,30	0,7	Object

SSS_175	723532,73	5954134,02	0,6	Object
SSS_176	723718,13	5954854,97	0,5	Object
SSS_177	723711,89	5954061,63	0,8	Object
SSS_178	723715,87	5954080,48	0,7	Object
SSS_179	723716,67	5954083,25	0,9	Object
SSS_180	723754,52	5953968,95	1,1	Object
SSS_181	723862,13	5954493,02	1	Object
SSS_182	723808,64	5953913,20	0,8	Object
SSS_183	723809,10	5953901,40	0,7	Object
SSS_184	723849,19	5954109,37	0,6	Object
SSS_185	723845,06	5953991,78	0,6	Object
SSS_186	723854,66	5954067,59	0,5	Object
SSS_187	723853,79	5954050,54	0,5	Object
SSS_188	723862,24	5954111,86	0,5	Object
SSS_189	723857,63	5954050,68	0,6	Object
SSS_190	723852,05	5953876,48	0,6	Object
SSS_191	723881,22	5953902,89	0,7	Object
SSS_192	723905,57	5954059,20	0,6	Object
SSS_193	723903,64	5953887,23	0,6	Object
SSS_194	723926,72	5954041,65	0,5	Object
SSS_195	723960,42	5954035,26	0,5	Object
SSS_196	723975,07	5954068,32	0,5	Object
SSS_197	724277,58	5954747,16	0,6	Object
SSS_198	724476,72	5953817,57	0,5	Object
SSS_199	724644,94	5954411,18	0,5	Object
SSS_200	724661,78	5954539,65	0,6	Object
SSS_201	724579,57	5953602,83	0,7	Object
SSS_202	724731,05	5954433,07	0,7	Object

SSS_203	724642,24	5953636,41	0,6	Object
SSS_204	724766,83	5954450,51	0,6	Object
SSS_205	724783,12	5954517,10	0,6	Object
SSS_206	724778,58	5954449,53	0,6	Object
SSS_207	724778,70	5954349,32	0,6	Object
SSS_208	724780,26	5953558,96	0,5	Object
SSS_209	724942,39	5954328,74	0,7	Object
SSS_210	724989,45	5954393,95	0,6	Object
SSS_211	725009,84	5954374,67	0,7	Object
SSS_212	725048,36	5954528,27	0,6	Object
SSS_213	724985,69	5953718,56	1,2	Object
SSS_214	725096,72	5954515,79	0,5	Object
SSS_215	725124,32	5954241,75	0,6	Object
SSS_216	725134,42	5954237,50	0,6	Object
SSS_217	725144,69	5954278,59	0,6	Object
SSS_218	725092,50	5953770,38	0,5	Object
SSS_219	725150,03	5954266,54	0,5	Object
SSS_220	725152,17	5954277,48	0,5	Object
SSS_221	725178,56	5954225,18	0,5	Object
SSS_222	725124,87	5953745,24	0,6	Object
SSS_223	725115,87	5953501,85	0,5	Object
SSS_224	725172,54	5953894,35	0,5	Object
SSS_225	725246,91	5954420,97	0,7	Object
SSS_226	725261,74	5954467,16	0,7	Object
SSS_227	725212,52	5953937,96	0,6	Object
SSS_228	725244,46	5954123,17	0,5	Object
SSS_229	725262,43	5954046,93	0,6	Object
SSS_230	725276,31	5954136,17	0,5	Object

SSS_231	725288,51	5954240,26	0,6	Object
SSS_232	725285,49	5954061,94	0,9	Object
SSS_233	725327,30	5954221,86	0,7	Object
SSS_234	725336,55	5954215,62	0,8	Object
SSS_235	725341,32	5954252,77	0,6	Object
SSS_236	725346,39	5954204,15	0,5	Object
SSS_237	725390,80	5954497,76	0,6	Object
SSS_238	725361,58	5954030,67	0,7	Object
SSS_239	725387,33	5954238,49	0,5	Object
SSS_240	725361,50	5953844,71	0,8	Object
SSS_241	725428,26	5954348,17	0,6	Object
SSS_242	725473,83	5954428,28	0,7	Object
SSS_243	725407,58	5953805,92	0,7	Object
SSS_244	725447,98	5953818,37	0,8	Object
SSS_245	725500,73	5954077,67	0,6	Object
SSS_246	725469,00	5953705,87	0,7	Object
SSS_247	725502,53	5953777,01	0,6	Object
SSS_248	725503,43	5953676,67	0,5	Object
SSS_249	725549,47	5953801,34	0,7	Object
SSS_250	725568,76	5953790,04	1,1	Object
SSS_251	725654,15	5954532,82	0,5	Object
SSS_252	725650,48	5954214,47	0,5	Object
SSS_253	725671,55	5954313,50	0,6	Object
SSS_254	725663,15	5954214,40	0,6	Object
SSS_255	725649,37	5953785,79	0,6	Object
SSS_256	725831,42	5954364,25	0,5	Object
SSS_257	725785,29	5953766,44	0,6	Object
SSS_258	725827,13	5953653,81	0,6	Object

SSS_259	725928,37	5954476,41	0,6	Object
SSS_260	725965,90	5954322,62	0,7	Object
SSS_261	725997,41	5953887,92	0,5	Object
SSS_262	726052,22	5954102,79	0,5	Object
SSS_263	726057,41	5954141,89	0,6	Object
SSS_264	726125,63	5954417,63	0,7	Object
SSS_265	726114,48	5954190,77	0,6	Object
SSS_266	726107,63	5954125,64	0,7	Object
SSS_267	726119,61	5954110,39	0,6	Object
SSS_268	726091,62	5953851,33	0,7	Object
SSS_269	726190,19	5954548,21	0,6	Object
SSS_270	726173,34	5954150,49	0,5	Object
SSS_271	726253,07	5954394,21	0,9	Object
SSS_272	726319,83	5954354,42	0,5	Object
SSS_273	726386,30	5954389,49	0,7	Object
SSS_274	726412,12	5954380,81	0,6	Object
SSS_275	726385,89	5954146,61	0,9	Object
SSS_276	726544,54	5954494,79	0,5	Object
SSS_277	726502,03	5954104,70	0,8	Object
SSS_278	726506,85	5954107,53	0,7	Object
SSS_279	726592,04	5954486,38	0,7	Object
SSS_280	726742,62	5954423,38	0,7	Object
SSS_281	726870,97	5954279,25	0,6	Object
SSS_282	726958,22	5954177,60	0,6	Object
SSS_283	726989,51	5954175,50	0,7	Object
SSS_284	727046,94	5954189,82	0,5	Object
SSS_285	727104,19	5954382,52	1,1	Object
SSS_286	729697,53	5955104,13	0,6	Object

SSS_287	729774,83	5955004,78	0,7	Object
SSS_288	729767,36	5955100,95	0,5	Object
SSS_289	729791,72	5955056,65	0,9	Object
SSS_290	729990,54	5955191,79	0,6	Object
SSS_291	730162,26	5955230,58	0,5	Object
SSS_292	730317,76	5955207,78	0,6	Object
SSS_293	730309,61	5955222,10	1,2	Object
SSS_294	730297,63	5955291,03	0,5	Object
SSS_295	730324,81	5955286,64	0,5	Object
SSS_296	730359,44	5955287,63	0,7	Object
SSS_297	730418,89	5955242,55	0,5	Object
SSS_298	730417,60	5955276,24	0,6	Object
SSS_299	730463,81	5955245,45	0,5	Object
SSS_300	730506,71	5955235,50	0,5	Object
SSS_301	730516,10	5955237,56	0,5	Object
SSS_302	730541,92	5955229,90	0,9	Object
SSS_303	730556,17	5955284,38	0,6	Object
SSS_304	730578,58	5955257,66	0,9	Object
SSS_305	730574,39	5955355,60	0,5	Object
SSS_306	721419,2	5954712,6	0,7	Object
SSS_307	721408,5	5954529,1	1,3	Object
SSS_308	721458,1	5954747,9	0,9	Object
SSS_309	721555,0	5954666,2	0,8	Object
SSS_310	721616,0	5954554,5	0,6	Object
SSS_311	721655,2	5954793,5	0,7	Object
SSS_312	721625,0	5954519,2	0,7	Object
SSS_313	721652,1	5954564,4	0,6	Object
SSS_314	721746,8	5954595,7	0,6	Object

SSS_315	721766,6	5954616,9	0,8	Object
SSS_316	721759,4	5954496,7	0,6	Object
SSS_317	721791,4	5954654,8	0,5	Object
SSS_318	721772,5	5954430,6	0,6	Object
SSS_319	721815,4	5954641,9	0,6	Object
SSS_320	721825,4	5954588,2	0,5	Object
SSS_321	721829,4	5954595,1	0,6	Object
SSS_322	721852,0	5954594,2	0,6	Object
SSS_323	721858,2	5954627,1	0,6	Object
SSS_324	721880,7	5954700,9	0,6	Object
SSS_325	721850,6	5954434,7	0,6	Object
SSS_326	721896,8	5954569,6	0,7	Object
SSS_327	721927,0	5954712,8	0,5	Object
SSS_328	721940,2	5954537,2	0,7	Object
SSS_329	722026,1	5954527,0	0,7	Object
SSS_330	722037,4	5954431,4	0,9	Object
SSS_331	722065,6	5954532,7	0,5	Object
SSS_332	722072,3	5954539,2	0,5	Object
SSS_333	722091,6	5954408,4	0,8	Object
SSS_334	722127,9	5954494,6	0,5	Object
SSS_335	722168,5	5954646,2	0,5	Object
SSS_336	722175,0	5954701,1	0,7	Object
SSS_337	722256,4	5954767,0	0,8	Object
SSS_338	722258,5	5954555,0	0,6	Object
SSS_339	722266,1	5954620,9	0,5	Object
SSS_340	722266,7	5954547,2	0,6	Object
SSS_341	722326,4	5954705,0	1,1	Object
SSS_342	722362,9	5954613,5	0,6	Object

SSS_343	722407,2	5954745,4	0,6	Object
SSS_344	723246,4	5954499,2	0,8	Object
SSS_345	723862,1	5954493,0	1	Object
SSS_346	724644,9	5954411,2	0,5	Object
SSS_347	724731,1	5954433,1	0,7	Object
SSS_348	724766,8	5954450,5	0,6	Object
SSS_349	724778,6	5954449,5	0,6	Object
SSS_350	724778,7	5954349,3	0,6	Object
SSS_351	724942,4	5954328,7	0,7	Object
SSS_352	724989,4	5954394,0	0,6	Object
SSS_353	725009,8	5954374,7	0,7	Object
SSS_354	725124,3	5954241,8	0,6	Object
SSS_355	725134,4	5954237,5	0,6	Object
SSS_356	725144,7	5954278,6	0,6	Object
SSS_357	725150,0	5954266,5	0,5	Object
SSS_358	725152,2	5954277,5	0,5	Object
SSS_359	725178,6	5954225,2	0,5	Object
SSS_360	725246,9	5954421,0	0,7	Object
SSS_361	725244,5	5954123,2	0,5	Object
SSS_362	725262,4	5954046,9	0,6	Object
SSS_363	725276,3	5954136,2	0,5	Object
SSS_364	725288,5	5954240,3	0,6	Object
SSS_365	725285,5	5954061,9	0,9	Object
SSS_366	725327,3	5954221,9	0,7	Object
SSS_367	725336,5	5954215,6	0,8	Object
SSS_368	725341,3	5954252,8	0,6	Object
SSS_369	725346,4	5954204,1	0,5	Object
SSS_370	725361,6	5954030,7	0,7	Object

SSS_371	725387,3	5954238,5	0,5	Object
SSS_372	725428,3	5954348,2	0,6	Object
SSS_373	725500,7	5954077,7	0,6	Object
SSS_374	725650,5	5954214,5	0,5	Object
SSS_375	725671,5	5954313,5	0,6	Object
SSS_376	725663,1	5954214,4	0,6	Object
SSS_377	725831,4	5954364,2	0,5	Object
SSS_378	725965,9	5954322,6	0,7	Object
SSS_379	726052,2	5954102,8	0,5	Object
SSS_380	726057,4	5954141,9	0,6	Object
SSS_381	726114,5	5954190,8	0,6	Object
SSS_382	726107,6	5954125,6	0,7	Object
SSS_383	726119,6	5954110,4	0,6	Object
SSS_384	726173,3	5954150,5	0,5	Object
SSS_385	726385,9	5954146,6	0,9	Object
SSS_386	726502,0	5954104,7	0,8	Object
SSS_387	726506,9	5954107,5	0,7	Object
SSS_388	726871,0	5954279,2	0,6	Object
SSS_389	726958,2	5954177,6	0,6	Object
SSS_390	726989,5	5954175,5	0,7	Object
SSS_391	727046,9	5954189,8	0,5	Object
SSS_392	727104,2	5954382,5	1,1	Object
SSS_393	729697,5	5955104,1	0,6	Object
SSS_394	729774,8	5955004,8	0,7	Object
SSS_395	729767,4	5955101,0	0,5	Object
SSS_396	729791,7	5955056,7	0,9	Object
SSS_397	729990,5	5955191,8	0,6	Object
SSS_398	721343,9	5954472,5	0,5	Object

SSS_399	721373,4	5954458,7	0,5	Object
SSS_400	721517,6	5954248,1	0,6	Object
SSS_401	721290,6	5954297,2	0,6	Object
SSS_402	721395,6	5954262,4	0,6	Object
SSS_403	721571,5	5954203,1	0,5	Object
SSS_404	721523,0	5954218,8	0,7	Object
SSS_405	721395,2	5954252,8	0,7	Object
SSS_406	721626,4	5954092,9	0,5	Object
SSS_407	721604,6	5954084,5	0,7	Object
SSS_408	721455,7	5954048,1	0,5	Object
SSS_409	721444,6	5954037,8	0,6	Object
SSS_410	721235,0	5954040,4	0,6	Object
SSS_411	721246,9	5953990,0	0,7	Object
SSS_412	721195,8	5953987,5	0,5	Object
SSS_413	721388,2	5953864,3	0,6	Object
SSS_414	721246,8	5953887,4	0,6	Object
SSS_415	721227,5	5953868,5	0,7	Object
SSS_416	721343,0	5953829,2	0,5	Object
SSS_417	721224,7	5953846,8	0,6	Object
SSS_418	721379,4	5953792,7	0,6	Object
SSS_419	721392,0	5953769,8	0,7	Object
SSS_420	721261,2	5953798,9	0,8	Object
SSS_421	721418,9	5953687,4	0,6	Object
SSS_422	721338,8	5953691,8	0,8	Object
SSS_423	721339,8	5953688,0	0,8	Object
SSS_424	721351,0	5953668,2	0,8	Object
SSS_425	721357,9	5953583,8	0,5	Object
SSS_426	721410,7	5953535,3	0,6	Object

SSS_427	718503,9	5942263,9	0,8	Object
SSS_428	720988,4	5954348,5	1	Object
SSS_429	721040	5954486,9	0,6	Object
SSS_430	721048,1	5954441	0,5	Object
SSS_431	721047,8	5954403,6	0,8	Object
SSS_432	721055,1	5954273,5	0,5	Object
SSS_433	721070	5954388	0,5	Object
SSS_434	721083,6	5954252,5	0,6	Object
SSS_435	721120,5	5954342,5	0,6	Object
SSS_436	721124,2	5954225,5	0,6	Object
SSS_437	721154,2	5954387,6	0,5	Object
SSS_438	721200,5	5954647,4	0,6	Object
SSS_439	721189,7	5954332	0,8	Object
SSS_440	721204,1	5954287,9	0,7	Object
SSS_441	721304,2	5954594,4	1	Object
SSS_442	721321,5	5954595,8	0,9	Object
SSS_443	721290,6	5954297,2	0,6	Object
SSS_444	721343,9	5954472,5	0,5	Object
SSS_445	721373,4	5954458,7	0,5	Object
SSS_446	721419,2	5954712,6	0,7	Object
SSS_447	721408,5	5954529,1	1,3	Object
SSS_448	721395,6	5954262,4	0,6	Object
SSS_449	721395,2	5954252,8	0,7	Object
SSS_450	721458,1	5954747,9	0,9	Object
SSS_451	721555	5954666,2	0,8	Object
SSS_452	721517,6	5954248,1	0,6	Object
SSS_453	721523	5954218,8	0,7	Object
SSS_454	721637,9	5954907,1	0,7	Object

SSS_455	721648,1	5954914,1	0,5	Object
SSS_456	721571,5	5954203,1	0,5	Object
SSS_457	721656,4	5954932,1	1	Object
SSS_458	721616	5954554,5	0,6	Object
SSS_459	721674,2	5955016,6	0,5	Object
SSS_460	721655,2	5954793,5	0,7	Object
SSS_461	721625	5954519,2	0,7	Object
SSS_462	721680,8	5955011	0,7	Object
SSS_463	721652,1	5954564,4	0,6	Object
SSS_464	721717,1	5954862,9	0,6	Object
SSS_465	721718,1	5954870,3	0,7	Object
SSS_466	721738,4	5955038,3	0,7	Object
SSS_467	721723,2	5954856,2	0,6	Object
SSS_468	721767,7	5955126	0,6	Object
SSS_469	721776	5955044,1	0,7	Object
SSS_470	721710,9	5954302,9	0,5	Object
SSS_471	721800,3	5955078,8	0,5	Object
SSS_472	721746,8	5954595,7	0,6	Object
SSS_473	721788,7	5954958,7	0,6	Object
SSS_474	721808,3	5955123,3	0,6	Object
SSS_475	721798,9	5954964,4	0,6	Object
SSS_476	721766,6	5954616,9	0,8	Object
SSS_477	721819,7	5955039,4	0,8	Object
SSS_478	721759,4	5954496,7	0,6	Object
SSS_479	721791,4	5954654,8	0,5	Object
SSS_480	721764,5	5954382,5	0,5	Object
SSS_481	721772,5	5954430,6	0,6	Object
SSS_482	721847,3	5954926	0,6	Object

SSS_483	721815,4	5954641,9	0,6	Object
SSS_484	721788,5	5954369,3	0,6	Object
SSS_485	721854,7	5954924,8	0,5	Object
SSS_486	721825,4	5954588,2	0,5	Object
SSS_487	721829,4	5954595,1	0,6	Object
SSS_488	721852	5954594,2	0,6	Object
SSS_489	721858,2	5954627,1	0,6	Object
SSS_490	721880,7	5954700,9	0,6	Object
SSS_491	721850,6	5954434,7	0,6	Object
SSS_492	721896,8	5954569,6	0,7	Object
SSS_493	721927	5954712,8	0,5	Object
SSS_494	721940,2	5954537,2	0,7	Object
SSS_495	721949,1	5954256,8	0,7	Object
SSS_496	722062	5954903,7	0,5	Object
SSS_497	722026,1	5954527	0,7	Object
SSS_498	722031,2	5954397,3	0,7	Object
SSS_499	722007,9	5954191,3	0,6	Object
SSS_500	722037,4	5954431,4	0,9	Object
SSS_501	722065,6	5954532,7	0,5	Object
SSS_502	722072,3	5954539,2	0,5	Object
SSS_503	722049,5	5954224,7	0,8	Object
SSS_504	722128,6	5954814,3	0,6	Object
SSS_505	722131,2	5954815	0,5	Object
SSS_506	722142	5954862	0,5	Object
SSS_507	722091,6	5954408,4	0,8	Object
SSS_508	722066,3	5954158	0,6	Object
SSS_509	722079,7	5954193,9	0,6	Object
SSS_510	722127,9	5954494,6	0,5	Object

SSS_511	722094,4	5954197,4	0,5	Object
SSS_512	722100,1	5954245	0,7	Object
SSS_513	722112,9	5954349,6	1	Object
SSS_514	722112,7	5954276	0,7	Object
SSS_515	722119,7	5954332,1	0,6	Object
SSS_516	722168,5	5954646,2	0,5	Object
SSS_517	722175	5954701,1	0,7	Object
SSS_518	722117	5954180,7	0,5	Object
SSS_519	722162	5954289,9	0,6	Object
SSS_520	722256,4	5954767	0,8	Object
SSS_521	722258,5	5954555	0,6	Object
SSS_522	722266,1	5954620,9	0,5	Object
SSS_523	722266,7	5954547,2	0,6	Object
SSS_524	722271,9	5954311,5	0,5	Object
SSS_525	722326,4	5954705	1,1	Object
SSS_526	722299,3	5954139,6	1	Object
SSS_527	722362,9	5954613,5	0,6	Object
SSS_528	722407,2	5954745,4	0,6	Object
SSS_529	722397,5	5954086,3	0,6	Object
SSS_530	722524,4	5954965,6	0,7	Object
SSS_531	722504,1	5954768,7	0,5	Object
SSS_532	722557,2	5954951,2	0,6	Object
SSS_533	722475,1	5954216	0,6	Object
SSS_534	722536,9	5954258,3	0,7	Object
SSS_535	722583,4	5954193,4	0,5	Object
SSS_536	722664,8	5954088,2	0,5	Object
SSS_537	722698,1	5954168,3	0,7	Object
SSS_538	723059,4	5954145,4	0,6	Object

SSS_539	723228,2	5954951,3	0,8	Object
SSS_540	723230,4	5954954,1	0,6	Object
SSS_541	723246,4	5954499,2	0,8	Object
SSS_542	723264,9	5954042,9	0,6	Object
SSS_543	723277,7	5953991,5	0,8	Object
SSS_544	723312,6	5954027,2	0,5	Object
SSS_545	723325,5	5954026,9	0,6	Object
SSS_546	723346,8	5954092,8	0,5	Object
SSS_547	723383,4	5954065,3	0,7	Object
SSS_548	723532,7	5954134	0,6	Object
SSS_549	723718,1	5954855	0,5	Object
SSS_550	723711,9	5954061,6	0,8	Object
SSS_551	723715,9	5954080,5	0,7	Object
SSS_552	723716,7	5954083,2	0,9	Object
SSS_553	723754,5	5953969	1,1	Object
SSS_554	723862,1	5954493	1	Object
SSS_555	723808,6	5953913,2	0,8	Object
SSS_556	723809,1	5953901,4	0,7	Object
SSS_557	723849,2	5954109,4	0,6	Object
SSS_558	723845,1	5953991,8	0,6	Object
SSS_559	723854,7	5954067,6	0,5	Object
SSS_560	723853,8	5954050,5	0,5	Object
SSS_561	723862,2	5954111,9	0,5	Object
SSS_562	723857,6	5954050,7	0,6	Object
SSS_563	723881,2	5953902,9	0,7	Object
SSS_564	723905,6	5954059,2	0,6	Object
SSS_565	723903,6	5953887,2	0,6	Object
SSS_566	723926,7	5954041,6	0,5	Object

SSS_567	723960,4	5954035,3	0,5	Object
SSS_568	723975,1	5954068,3	0,5	Object
SSS_569	724277,6	5954747,2	0,6	Object
SSS_570	724644,9	5954411,2	0,5	Object
SSS_571	724661,8	5954539,6	0,6	Object
SSS_572	724731,1	5954433,1	0,7	Object
SSS_573	724766,8	5954450,5	0,6	Object
SSS_574	724783,1	5954517,1	0,6	Object
SSS_575	724778,6	5954449,5	0,6	Object
SSS_576	724778,7	5954349,3	0,6	Object
SSS_577	724942,4	5954328,7	0,7	Object
SSS_578	724989,4	5954394	0,6	Object
SSS_579	725009,8	5954374,7	0,7	Object
SSS_580	725048,4	5954528,3	0,6	Object
SSS_581	725096,7	5954515,8	0,5	Object
SSS_582	725124,3	5954241,8	0,6	Object
SSS_583	725134,4	5954237,5	0,6	Object
SSS_584	725144,7	5954278,6	0,6	Object
SSS_585	725092,5	5953770,4	0,5	Object
SSS_586	725150	5954266,5	0,5	Object
SSS_587	725152,2	5954277,5	0,5	Object
SSS_588	725178,6	5954225,2	0,5	Object
SSS_589	725172,5	5953894,4	0,5	Object
SSS_590	725246,9	5954421	0,7	Object
SSS_591	725261,7	5954467,2	0,7	Object
SSS_592	725212,5	5953938	0,6	Object
SSS_593	725244,5	5954123,2	0,5	Object
SSS_594	725262,4	5954046,9	0,6	Object

SSS_595	725276,3	5954136,2	0,5	Object
SSS_596	725288,5	5954240,3	0,6	Object
SSS_597	725285,5	5954061,9	0,9	Object
SSS_598	725327,3	5954221,9	0,7	Object
SSS_599	725336,5	5954215,6	0,8	Object
SSS_600	725341,3	5954252,8	0,6	Object
SSS_601	725346,4	5954204,1	0,5	Object
SSS_602	725390,8	5954497,8	0,6	Object
SSS_603	725361,6	5954030,7	0,7	Object
SSS_604	725387,3	5954238,5	0,5	Object
SSS_605	725361,5	5953844,7	0,8	Object
SSS_606	725428,3	5954348,2	0,6	Object
SSS_607	725473,8	5954428,3	0,7	Object
SSS_608	725407,6	5953805,9	0,7	Object
SSS_609	725448	5953818,4	0,8	Object
SSS_610	725500,7	5954077,7	0,6	Object
SSS_611	725502,5	5953777	0,6	Object
SSS_612	725549,5	5953801,3	0,7	Object
SSS_613	725568,8	5953790	1,1	Object
SSS_614	725654,1	5954532,8	0,5	Object
SSS_615	725650,5	5954214,5	0,5	Object
SSS_616	725671,5	5954313,5	0,6	Object
SSS_617	725663,1	5954214,4	0,6	Object
SSS_618	725649,4	5953785,8	0,6	Object
SSS_619	725831,4	5954364,2	0,5	Object
SSS_620	725785,3	5953766,4	0,6	Object
SSS_621	725928,4	5954476,4	0,6	Object
SSS_622	725965,9	5954322,6	0,7	Object

SSS_623	725997,4	5953887,9	0,5	Object
SSS_624	726052,2	5954102,8	0,5	Object
SSS_625	726057,4	5954141,9	0,6	Object
SSS_626	726125,6	5954417,6	0,7	Object
SSS_627	726114,5	5954190,8	0,6	Object
SSS_628	726107,6	5954125,6	0,7	Object
SSS_629	726119,6	5954110,4	0,6	Object
SSS_630	726091,6	5953851,3	0,7	Object
SSS_631	726190,2	5954548,2	0,6	Object
SSS_632	726173,3	5954150,5	0,5	Object
SSS_633	726253,1	5954394,2	0,9	Object
SSS_634	726319,8	5954354,4	0,5	Object
SSS_635	726386,3	5954389,5	0,7	Object
SSS_636	726412,1	5954380,8	0,6	Object
SSS_637	726385,9	5954146,6	0,9	Object
SSS_638	726544,5	5954494,8	0,5	Object
SSS_639	726502	5954104,7	0,8	Object
SSS_640	726506,9	5954107,5	0,7	Object
SSS_641	726592	5954486,4	0,7	Object
SSS_642	726742,6	5954423,4	0,7	Object
SSS_643	726871	5954279,2	0,6	Object
SSS_644	726958,2	5954177,6	0,6	Object
SSS_645	726989,5	5954175,5	0,7	Object
SSS_646	727046,9	5954189,8	0,5	Object
SSS_647	727104,2	5954382,5	1,1	Object
SSS_648	729697,5	5955104,1	0,6	Object
SSS_649	729774,8	5955004,8	0,7	Object
SSS_650	729767,4	5955101	0,5	Object

SSS_651	729791,7	5955056,7	0,9	Object
SSS_652	729990,5	5955191,8	0,6	Object
SSS_653	730162,3	5955230,6	0,5	Object
SSS_654	730317,8	5955207,8	0,6	Object
SSS_655	730309,6	5955222,1	1,2	Object
SSS_656	730297,6	5955291	0,5	Object
SSS_657	730324,8	5955286,6	0,5	Object
SSS_658	730359,4	5955287,6	0,7	Object
SSS_659	730418,9	5955242,5	0,5	Object
SSS_660	730417,6	5955276,2	0,6	Object
SSS_661	730463,8	5955245,5	0,5	Object
SSS_662	730506,7	5955235,5	0,5	Object
SSS_663	730516,1	5955237,6	0,5	Object
SSS_664	721968,2	5955304,0	0,5	Object
SSS_665	721381,2	5955392,9	1,1	Object
SSS_666	721801,8	5955134,4	0,7	Object
SSS_667	721796,0	5955132,2	0,8	Object
SSS_668	721808,3	5955123,3	0,6	Object
SSS_669	721767,7	5955126,0	0,6	Object
SSS_670	721800,3	5955078,8	0,5	Object
SSS_671	721819,7	5955039,4	0,8	Object
SSS_672	721776,0	5955044,1	0,7	Object
SSS_673	721738,4	5955038,3	0,7	Object
SSS_674	722062,0	5954903,7	0,5	Object
SSS_675	721674,2	5955016,6	0,5	Object
SSS_676	722142,0	5954862,0	0,5	Object
SSS_677	721680,8	5955011,0	0,7	Object
SSS_678	721798,9	5954964,4	0,6	Object

SSS_679	721788,7	5954958,7	0,6	Object
SSS_680	721854,7	5954924,8	0,5	Object
SSS_681	721847,3	5954926,0	0,6	Object
SSS_682	722131,2	5954815,0	0,5	Object
SSS_683	722128,6	5954814,3	0,6	Object
SSS_684	721656,4	5954932,1	1	Object
SSS_685	721648,1	5954914,1	0,5	Object
SSS_686	721637,9	5954907,1	0,7	Object
SSS_687	721718,1	5954870,3	0,7	Object
SSS_688	721717,1	5954862,9	0,6	Object
SSS_689	721723,2	5954856,2	0,6	Object
SSS_690	722031,2	5954397,3	0,7	Object
SSS_691	721200,5	5954647,4	0,6	Object
SSS_692	721321,5	5954595,8	0,9	Object
SSS_693	721304,2	5954594,4	1	Object
SSS_694	721764,5	5954382,5	0,5	Object
SSS_695	721788,5	5954369,3	0,6	Object
SSS_696	721949,1	5954256,8	0,7	Object
SSS_697	721710,9	5954302,9	0,5	Object
SSS_698	721040,0	5954486,9	0,6	Object
SSS_699	721048,1	5954441,0	0,5	Object
SSS_700	721154,2	5954387,6	0,5	Object
SSS_701	721047,8	5954403,6	0,8	Object
SSS_702	721070,0	5954388,0	0,5	Object
SSS_703	721189,7	5954332,0	0,8	Object
SSS_704	721120,5	5954342,5	0,6	Object
SSS_705	721204,1	5954287,9	0,7	Object
SSS_706	720988,4	5954348,5	1	Object

SSS_707	721712,6	5954066,9	1	Object
SSS_708	721055,1	5954273,5	0,5	Object
SSS_709	721083,6	5954252,5	0,6	Object
SSS_710	721625,4	5954063,7	0,7	Object
SSS_711	721124,2	5954225,5	0,6	Object
SSS_712	721202,4	5954182,9	0,6	Object
SSS_713	721183,4	5954184,2	0,5	Object
SSS_714	721704,6	5954008,3	0,5	Object
SSS_715	721200,1	5954168,3	0,5	Object
SSS_716	721810,1	5953955,7	0,7	Object
SSS_717	721014,9	5954205,5	0,5	Object
SSS_718	721703,8	5953951,7	0,9	Object
SSS_719	721684,5	5953956,4	1,6	Object
SSS_720	721624,6	5953973,0	0,7	Object
SSS_721	721047,7	5954157,2	0,8	Object
SSS_722	721014,6	5954144,9	0,6	Object
SSS_723	721096,7	5954103,8	0,6	Object
SSS_724	721166,4	5954080,7	0,7	Object
SSS_725	721023,6	5954124,1	0,8	Object
SSS_726	721147,7	5954077,6	0,5	Object
SSS_727	721031,8	5954112,7	0,6	Object
SSS_728	721077,9	5954055,2	0,5	Object
SSS_729	721129,5	5954019,2	0,7	Object
SSS_730	720987,9	5954062,2	0,9	Object
SSS_731	721567,9	5953867,9	0,6	Object
SSS_732	721111,5	5954015,6	0,6	Object
SSS_733	721108,5	5954016,1	1	Object
SSS_734	720995,1	5954033,9	0,8	Object

SSS_735	721039,2	5954011,5	0,5	Object
SSS_736	721082,9	5953986,7	0,5	Object
SSS_737	721072,1	5953895,1	0,6	Object
SSS_738	720316,0	5950031,5	0,9	Object
SSS_739	720114,5	5948971,1	0,8	Object
SSS_740	719671,1	5947933,0	0,6	Object
SSS_741	718851,9	5942574,8	0,5	Object
SSS_742	722065,602	5954532,748	0,5	Object
SSS_743	721847,333	5954926,036	0,6	Object
SSS_744	721718,052	5954870,335	0,7	Object
SSS_745	721723,219	5954856,189	0,6	Object
SSS_746	721523,033	5954218,829	0,7	Object
SSS_747	721517,576	5954248,052	0,6	Object
SSS_748	721717,093	5954862,856	0,6	Object
SSS_749	721395,154	5954252,774	0,7	Object
SSS_750	721395,633	5954262,425	0,6	Object
SSS_751	721321,532	5954595,757	0,9	Object
SSS_752	721738,417	5955038,276	0,7	Object
SSS_753	721767,685	5955125,998	0,6	Object
SSS_754	721800,267	5955078,779	0,5	Object
SSS_755	721200,485	5954647,373	0,6	Object
SSS_756	721710,894	5954302,916	0,5	Object
SSS_757	721759,398	5954496,665	0,6	Object
SSS_758	721815,378	5954641,854	0,6	Object
SSS_759	721940,171	5954537,155	0,7	Object
SSS_760	722072,284	5954539,197	0,5	Object
SSS_761	721571,489	5954203,118	0,5	Object
SSS_762	722031,163	5954397,323	0,7	Object

SSS_763	721764,507	5954382,525	0,5	Object
SSS_764	721788,498	5954369,264	0,6	Object
SSS_765	722112,914	5954349,566	1	Object
SSS_766	721656,392	5954932,107	1	Object
SSS_767	721788,653	5954958,655	0,6	Object
SSS_768	721896,799	5954569,624	0,7	Object
SSS_769	721819,678	5955039,442	0,8	Object
SSS_770	721775,982	5955044,12	0,7	Object
SSS_771	721808,335	5955123,298	0,6	Object
SSS_772	721458,055	5954747,893	0,9	Object
SSS_773	721880,655	5954700,943	0,6	Object
SSS_774	721554,962	5954666,225	0,8	Object
SSS_775	722119,708	5954332,113	0,6	Object
SSS_776	721637,887	5954907,072	0,7	Object
SSS_777	721625,005	5954519,167	0,7	Object
SSS_778	721419,153	5954712,644	0,7	Object
SSS_779	721746,755	5954595,746	0,6	Object
SSS_780	721766,615	5954616,901	0,8	Object
SSS_781	721825,401	5954588,196	0,5	Object
SSS_782	721851,994	5954594,191	0,6	Object
SSS_783	721854,677	5954924,845	0,5	Object
SSS_784	722037,385	5954431,371	0,9	Object
SSS_785	722026,142	5954527,01	0,7	Object
SSS_786	721290,573	5954297,188	0,6	Object
SSS_787	721343,864	5954472,532	0,5	Object
SSS_788	721373,402	5954458,692	0,5	Object
SSS_789	721408,521	5954529,082	1,3	Object
SSS_790	721829,398	5954595,074	0,6	Object

SSS_791	721652,063	5954564,38	0,6	Object
SSS_792	721791,384	5954654,785	0,5	Object
SSS_793	721798,859	5954964,393	0,6	Object
SSS_794	721648,134	5954914,129	0,5	Object
SSS_795	721796,007	5955132,171	0,8	Object
SSS_796	721655,249	5954793,462	0,7	Object
SSS_797	721304,212	5954594,415	1	Object
SSS_798	721674,177	5955016,59	0,5	Object
SSS_799	721949,132	5954256,82	0,7	Object
SSS_800	721850,605	5954434,709	0,6	Object
SSS_801	721680,772	5955011,048	0,7	Object
SSS_802	721858,183	5954627,117	0,6	Object
WRECK_001	720537,7	5952510,7	19.1x12.9x0.2	Wreck
WRECK_002	720467,1	5952450,6	40.1x12.8x1.1	Wreck

B. Directional wave scatter

Monthly and All-year Joint Frequency Distributions of Hs and Mdir

All-Year

Significant Wave Height [m]	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	22.27	10.00	2.97	1.81	1.75	3.29	17.18	40.73	100.00	
> 4.00								<0.01	<0.01	
3.75–4.00	<0.01							0.14	0.14	0.14
3.50–3.75	0.03							0.49	0.52	0.67
3.25–3.50	0.05							0.91	0.96	1.63
3.00–3.25	0.11						<0.01	1.31	1.42	3.05
2.75–3.00	0.18						<0.01	1.39	1.58	4.63
2.50–2.75	0.26						0.04	1.40	1.71	6.34
2.25–2.50	0.32	<0.01					0.12	1.78	2.22	8.56
2.00–2.25	0.43	0.03				<0.01	0.32	2.18	2.97	11.53
1.75–2.00	0.65	0.06				<0.01	0.57	2.70	3.99	15.51
1.50–1.75	1.16	0.22	0.01	<0.01	<0.01	0.04	1.23	3.48	6.14	21.65
1.25–1.50	1.94	0.54	0.04	<0.01	0.01	0.11	2.16	4.51	9.32	30.97
1.00–1.25	3.04	1.15	0.16	0.03	0.08	0.37	2.91	5.46	13.20	44.18
0.75–1.00	4.71	1.99	0.49	0.21	0.33	0.80	3.38	5.88	17.78	61.95
0.50–0.75	5.46	2.92	1.06	0.67	0.68	1.07	3.70	5.28	20.83	82.78
0.25–0.50	3.53	2.64	1.01	0.75	0.57	0.78	2.39	3.43	15.09	97.87
0.00–0.25	0.41	0.46	0.19	0.15	0.07	0.12	0.34	0.39	2.13	

Mean Wave Direction [°T From]

All-Year

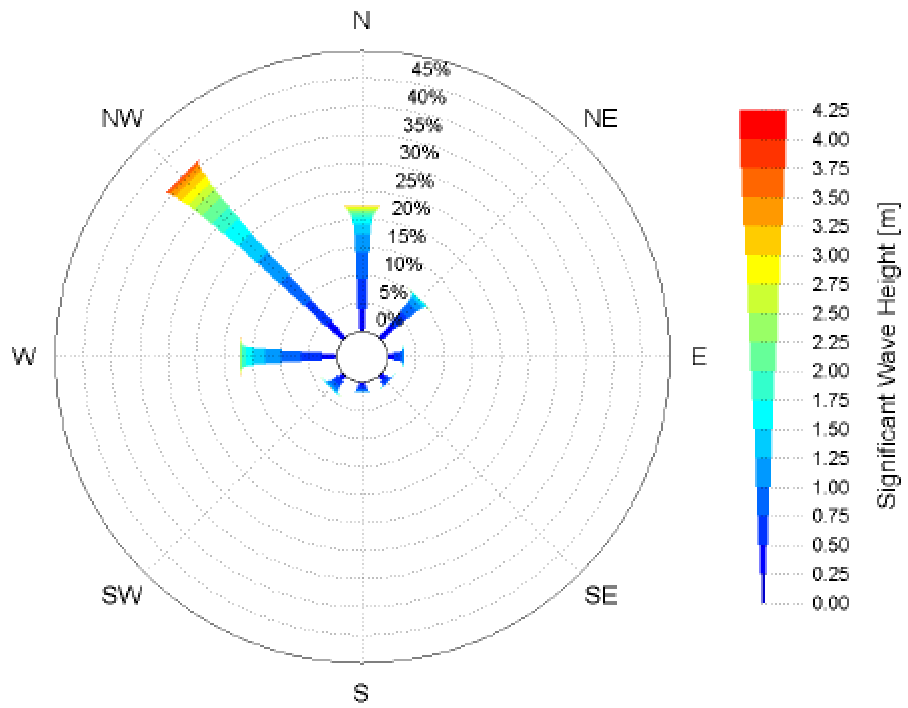


Figure B-1: Near platform wave scatter [ref II]

All-Year

Current Speed at 0m [m/s]	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	2.05	3.60	44.83	1.01	0.30	0.60	41.81	5.80	100.00	
1.10			<0.01						<0.01	
1.05			<0.01				<0.01		<0.01	
1.00			0.02				<0.01		0.02	0.03
0.95			0.06				<0.01		0.06	0.10
0.90			0.16				<0.01		0.17	0.27
0.85			0.55				0.02		0.57	0.84
0.80			1.57				0.04		1.62	2.46
0.75			2.95				0.09		3.04	5.50
0.70			3.87				0.25		4.12	9.62
0.65			4.41				1.14		5.55	15.17
0.60			4.63				2.78		7.41	22.58
0.55			4.25				4.09	<0.01	8.34	30.93
0.50		<0.01	3.72	<0.01		<0.01	4.87	<0.01	8.59	39.52
0.45		<0.01	3.26	<0.01			5.18	0.02	8.46	47.98
0.40		<0.01	2.91	<0.01		<0.01	5.04	0.06	8.02	56.01
0.35		0.02	2.62	<0.01		<0.01	4.55	0.14	7.33	63.34
0.30	<0.01	0.05	2.38	0.02		<0.01	3.89	0.31	6.65	69.99
0.25	0.01	0.14	2.22	0.04	<0.01	<0.01	3.12	0.56	6.09	76.06
0.20	0.05	0.36	1.92	0.07	<0.01	0.02	2.42	0.94	5.78	81.86
0.15	0.18	0.82	1.48	0.12	<0.01	0.04	1.78	1.34	5.77	87.63
0.10	0.65	1.26	1.00	0.20	0.03	0.09	1.31	1.46	5.99	93.61
0.05	0.96	0.76	0.62	0.32	0.09	0.20	0.89	0.75	4.60	98.21
0.00	0.19	0.19	0.24	0.23	0.17	0.24	0.32	0.21	1.79	

Current Direction at 0m [°T Towards]

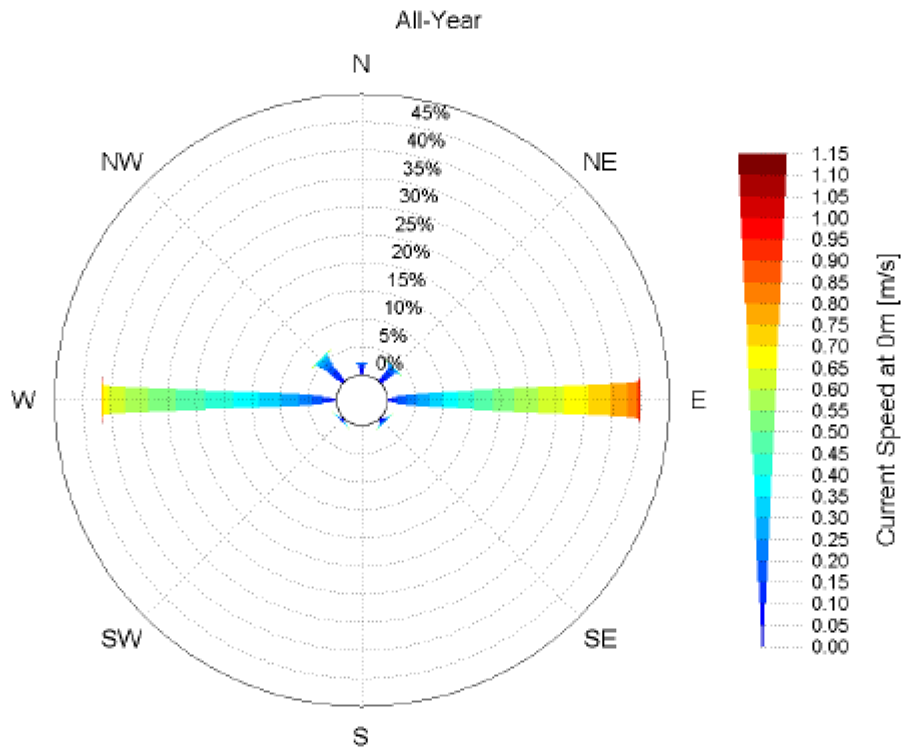
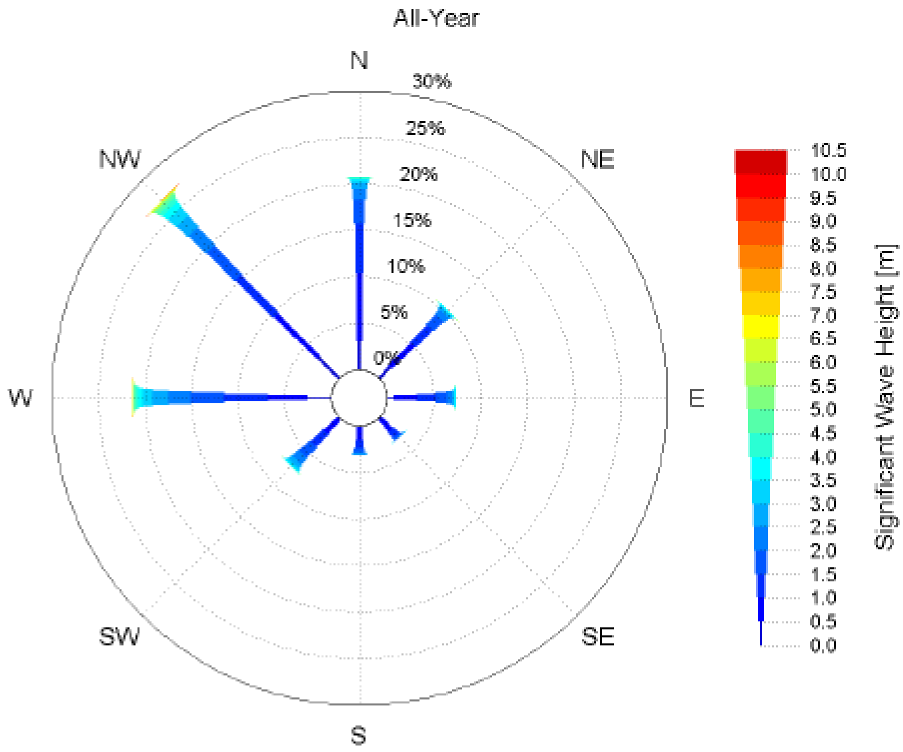


Figure B-2: Near platform current scatter [ref II]

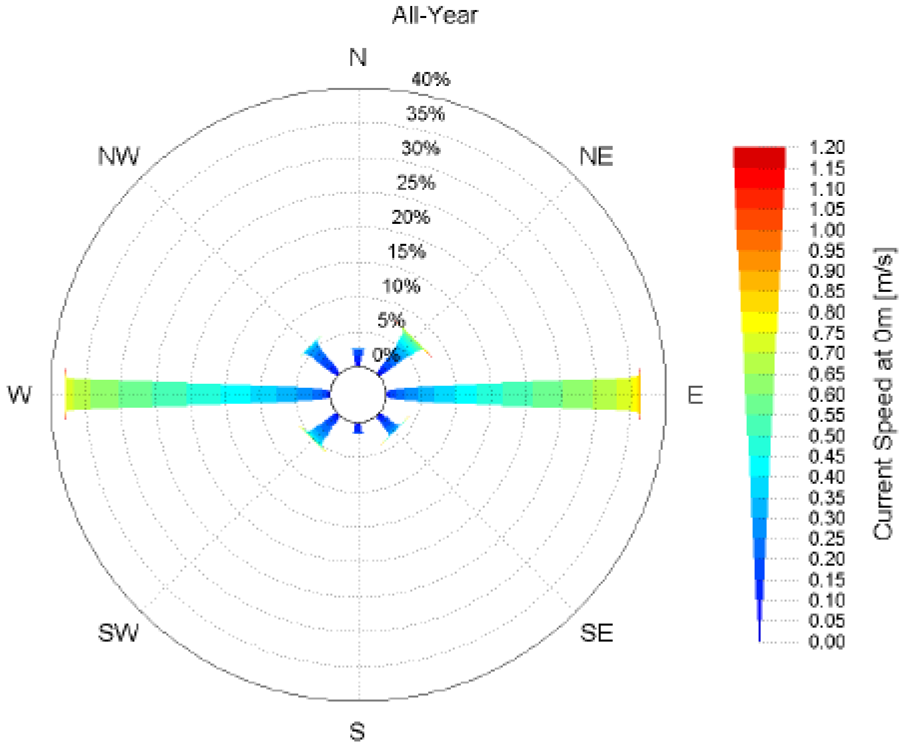


All-Year

Significant Wave Height [m]	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	20.79	10.32	7.24	2.97	3.14	7.30	21.26	26.98	100.00	
10.0–10.5								<0.01	<0.01	
9.5–10.0										
9.0–9.5										
8.5–9.0								<0.01	<0.01	
8.0–8.5	<0.01							0.02	0.02	0.02
7.5–8.0	<0.01							0.01	0.01	0.04
7.0–7.5	<0.01						<0.01	0.02	0.03	0.06
6.5–7.0	<0.01						<0.01	0.04	0.05	0.11
6.0–6.5	0.01						<0.01	0.05	0.07	0.19
5.5–6.0	0.02	<0.01					0.02	0.11	0.15	0.34
5.0–5.5	0.04	<0.01					0.06	0.19	0.29	0.63
4.5–5.0	0.06	<0.01				<0.01	0.14	0.34	0.54	1.18
4.0–4.5	0.08	0.03	<0.01			0.02	0.26	0.47	0.86	2.03
3.5–4.0	0.19	0.08	0.03		<0.01	0.07	0.55	0.72	1.65	3.68
3.0–3.5	0.33	0.15	0.11	<0.01	0.01	0.24	1.03	1.12	3.00	6.68
2.5–3.0	0.62	0.28	0.24	0.01	0.04	0.52	1.66	1.68	5.05	11.73
2.0–2.5	1.18	0.63	0.55	0.09	0.19	0.93	2.39	2.66	8.62	20.35
1.5–2.0	2.50	1.47	1.10	0.30	0.44	1.51	3.59	4.22	15.13	35.48
1.0–1.5	5.38	2.57	2.00	0.79	0.87	1.95	4.64	5.78	23.97	59.45
0.5–1.0	7.29	3.44	2.46	1.54	1.43	1.87	4.29	6.30	28.62	88.07
0.0–0.5	3.08	1.64	0.75	0.25	0.17	0.19	2.61	3.24	11.93	

Mean Wave Direction [°T From]

Figure B-3: Near tie-in wave scatter [ref III]



All-Year

Current Speed at 0m [m/s]	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	2.56	7.29	36.34	3.37	1.69	5.05	37.96	5.75	100.00	
1.15–			<0.01				<0.01		<0.01	
1.10–1.15		<0.01	<0.01				<0.01		<0.01	
1.05–1.10		<0.01	<0.01				<0.01		<0.01	
1.00–1.05		<0.01	<0.01				<0.01		<0.01	0.01
0.95–1.00		<0.01	0.01				<0.01		0.02	0.03
0.90–0.95		<0.01	0.03				0.01		0.05	0.08
0.85–0.90		<0.01	0.10				0.01		0.12	0.20
0.80–0.85		<0.01	0.30	<0.01			0.04		0.35	0.55
0.75–0.80		0.02	0.88	<0.01		<0.01	0.17		1.07	1.62
0.70–0.75		0.03	2.13	<0.01		<0.01	0.90		3.06	4.69
0.65–0.70		0.07	3.46	<0.01		<0.01	2.49		6.02	10.71
0.60–0.65		0.12	4.19	<0.01		<0.01	4.07		8.39	19.09
0.55–0.60		0.21	4.41	<0.01		<0.01	4.79	<0.01	9.42	28.51
0.50–0.55		0.32	4.20	<0.01		0.03	4.91	<0.01	9.46	37.98
0.45–0.50		0.43	3.73	<0.01	<0.01	0.07	4.80	<0.01	9.04	47.01
0.40–0.45		0.53	3.23	<0.01	<0.01	0.20	4.34	0.04	8.35	55.36
0.35–0.40	<0.01	0.61	2.81	0.04	<0.01	0.36	3.73	0.16	7.70	63.07
0.30–0.35	<0.01	0.72	2.35	0.14	<0.01	0.56	2.97	0.39	7.13	70.19
0.25–0.30	0.04	0.84	1.85	0.36	<0.01	0.78	2.13	0.78	6.78	76.98
0.20–0.25	0.24	0.97	1.31	0.70	0.03	0.97	1.36	1.22	6.81	83.79
0.15–0.20	0.71	0.99	0.78	0.98	0.36	1.05	0.72	1.49	7.09	90.88
0.10–0.15	0.89	0.87	0.38	0.80	0.85	0.72	0.33	1.13	5.97	96.85
0.05–0.10	0.59	0.47	0.14	0.28	0.38	0.25	0.14	0.46	2.72	99.57
0.00–0.05	0.09	0.07	0.03	0.04	0.05	0.04	0.03	0.07	0.43	

Current Direction at 0m [°T Towards]

Figure B-4: Near tie-in current scatter [ref III]

N05A Development Project

Pipeline Design and Installation Options

DOCUMENT NUMBER:

N05A-7-10-0-70037-01

Rev.	Date	Description	Originator	Checker	Approver
00	06-12-2019	For internal review	FGR	JWA	JWA
01	20-12-2019	For internal use	FGR	JWA	JWA
02	07-01-2020	Approved for Internal use	FGR	JWA	JWA
03	27-01-2020	Updated for Internal use	FGR	JWA	JWA

TABLE OF CONTENTS:

1.0 INTRODUCTION

One-Dyas plans to develop a successfully drilled well in block N5a of the North Sea Dutch Continental Shelf. More wells will be drilled at this location through the same jacket. It is planned to develop the wells by installing a platform and a gas export pipeline with a connection to the NGT pipeline. Various alternatives for the export pipeline route have been evaluated and a preferred route has been selected for further development; Pipeline route from the future N5A platform location to a subsea hot-tap tie-in at the NGT pipeline near KP 142.1.
In addition, a power cable will be installed from the Riffgat Windpark to the N05A platform.

Regarding installation of the N05a gas export pipeline many stakeholders are involved. In order to select the best technical solution for installation of the pipeline, with consideration of stakeholder requirements, this document has been written.

2.0 SELECTED PIPELINE DIAMETER

Our pipeline design contractor has carried out flow assurance analyses for 16 inch, 20 inch and 24 inch pipeline diameters. Based on these analyses a 20 inch pipeline diameter has been selected, which has more than sufficient capacity for the predicted N05a gas production.
An overview of the flow assurance results is given in table 2.1 below.

Table 2.1: Flow assurance results overview for 90 bar NGT pipeline pressure

		ND	ID	Gas flow		
#	Cases	inch	mm	MMNm^3/d	Graphic Legend	Colour
1	16inch-001 Design	16	0.3635	6.0	Design-16"-6.0MMNm3d	
2	20inch-002 Design	20	0.4556	6.0	Design-20"-6.0MMNm3d	
40	24inch-040 Design	24	0.54808	6.0	Design-24"-6.0MMNm3d	
3	16inch-003 SOL	16	0.3635	4.0	SOL-16"-4.0MMNm3d	
4	20inch-004 SOL	20	0.4556	4.0	SOL-20"-4.0MMNm3d	
41	24inch-041 SOL	24	0.54808	4.0	SOL-24"-4.0MMNm3d	
7	16inch-007 EOL	16	0.3635	0.1	EOL-16"-0.1MMNm3d	
8	20inch-008 EOL	20	0.4556	0.1	EOL-20"-0.1MMNm3d	
43	24inch-043 EOL	24	0.54808	0.1	EOL-24"-0.1MMNm3d	
9	16inch-009 Max OP	16	0.3635	5.2	MaxOP-16"-5.2MMNm3d	
10	20inch-010 max OP	20	0.4556	9.3	MaxOP-20"-9.3MMNm3d	
44	24inch-044 max OP	24	0.54808	15.0	MaxOP-24"-15.0MMNm3d	
11	16inch-011 Max Design	16	0.3635	7.8	MaxD-16"-7.8MMNm3d	
12	20inch-012 Max Design	20	0.4556	14.0	MaxD-20"-14.0MMNm3d	
45	24inch-045 Max Design	24	0.54808	22.7	MaxD-24"-22.7MMNm3d	

3.0 PIPELINE ROUTE

A pipeline and cable route survey has been carried out comprising of the following elements:

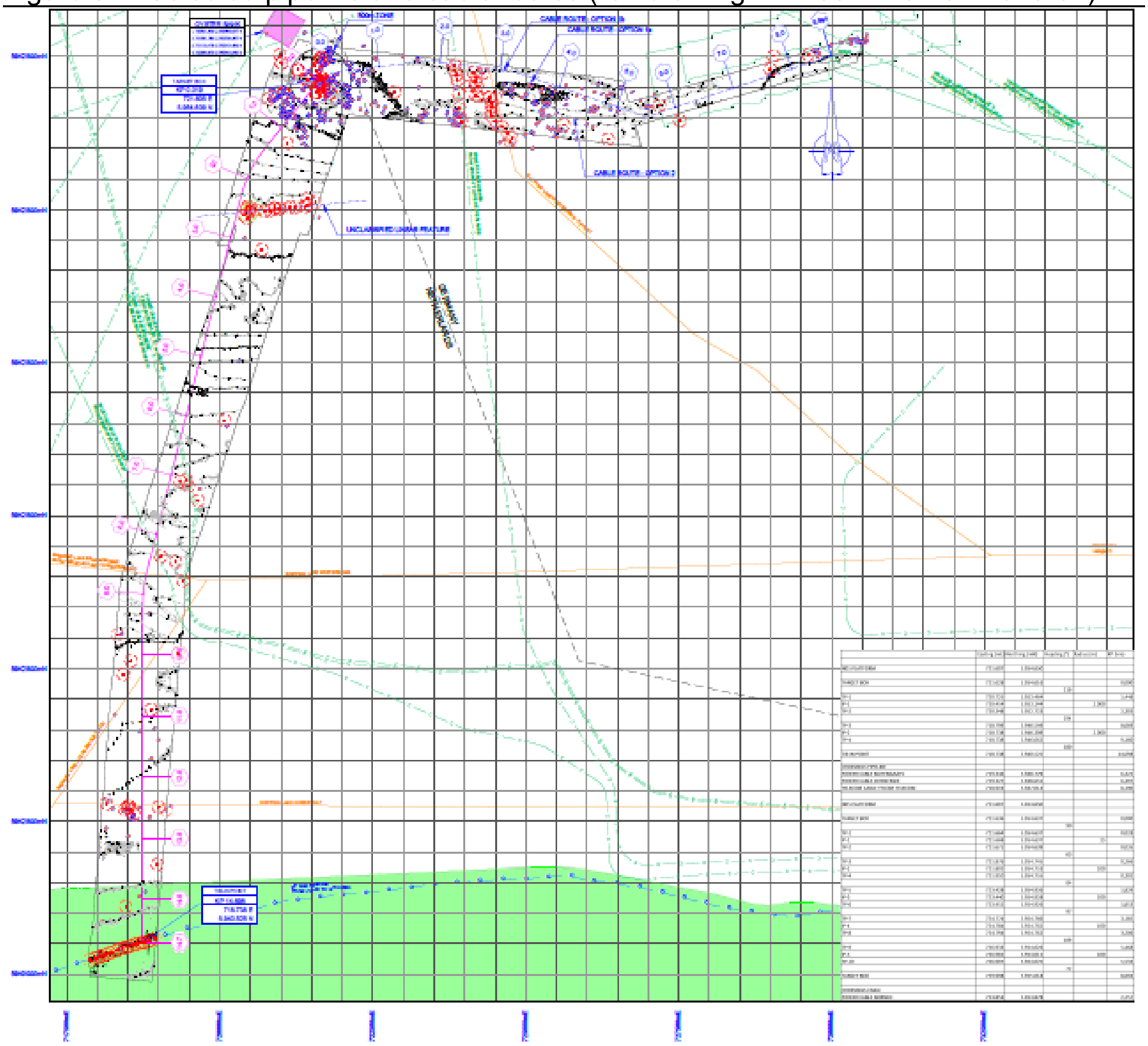
- Geophysical survey of a 1km wide corridor
- Geotechnical survey at 1km intervals
- Environmental baseline survey
- Archaeological desk top study using database information and recent survey information.

Based on the survey results pipeline and power cable route has been selected taking the following in consideration:

- 100m minimum distance to magnetic contacts
- 150m minimum distance to wrecks
- 25m minimum distance to remaining anomalies such as boulders

RWS have confirmed that they have no objections to the selected pipeline route and Periplus, who performs the archaeological study, have verbally confirmed that the route is acceptable with respect to possible archaeological values.

Figure 3.1: Selected pipeline and cable routes (ref. drawing nr. N05A-7-51-0-72510-01)



4.0 PIPELINE STABILITY

4.1 Unburied Pipeline Stability

Due to high currents and waves along the N05a pipeline route, specifically in the shallow part, a thick concrete weight coating is required to make an unburied pipeline stable. The calculated required concrete weight coating thickness is 140mm, with a density of 3300kg/m3. Even with this heavy weight coating the pipeline moves considerably. Based on DNV rules the pipeline moves over a distance of 10 times OD which is approximately 5m. To determine pipeline movement more accurately a finite element method has been used with an estimated pipeline embedment of 25%. Even with this embedment it was calculated that the pipeline moves more than 8m in the 10000 year storm conditions. To make the pipeline stable an even thicker concrete weight coating will be required beyond 200mm, which is a technically not achievable, as confirmed by pipe coaters Renania/Conline.

4.2 Buried Pipeline Stability

A buried pipeline does not require weight coating to be stable. During installation, when laying on the seabed before it is buried, a 20 inch pipeline without concrete weight coating is not stable in the 1 year storm. However, this can and will be managed by the installation contractor, using a favorable installation weather window. The pipeline will be buried directly after installation and it will then be stable in the 10.000 year storm. To enhance pipeline trenching it will be beneficial to apply a thin layer of 40mm concrete weight coating on the pipeline. This will also improve impact protection, pipeline stability before trenching and mitigate possible liquefaction.

5.0 RISK ASSESMENT

A risk assessment has been carried out by our pipeline design Contractor, for the buried and unburied pipeline options. Detailed results are given in document number N05A-7-10-0-70030-01 “Risk assessment & dropped object analysis”. A 1m deep buried pipeline without concrete weight coating is a safer option than an unburied pipeline with 140mm concrete weight coating. The latter option is not in accordance with the NEN3656 fail chance threshold of 1 x 10^{-6} per km of pipeline, per year.

Table 5.1 Quantitative Risk Assessment Results (ref. doc. Nr. N05A-7-10-0-70030-01)

	Failure chance per km per year					
Ship density /1000 km^2	**Un-buried case 140 mm CWC**	**Buried 0.6 m**	**Buried 0.7 m**	**Buried 0.8 m**	**Buried 1.0 m**	**NEN 3656 compliant**
45	3.39 10^{-6}	1.21 10^{-6}	1.00 10^{-6}	0.79 10^{-6}	0.78 10^{-6}	No / Yes

6.0 REQUIRED INSTALLATION SPREAD

6.1 General

Due to the limited waterdepth of 8m LAT near the future NGT pipeline tie-in point it is not feasible to install the pipeline with a dynamic positioned pipelay vessel. The thrusters underneath DP vessels they require a minimum waterdepth of approximately 17m LAT. Hence, the N05a pipeline will have to be installed by a shallow water pipelay barge operating on anchors.

These barges are towed to location by tugs, which will be used to position and relocate anchors when the vessel is on location. The range of shallow water pipelay barges available in the North Sea is limited to the Allseas Tog Mor and the Stingray owned by Van Oord. Possibly the Saipem owned Castoro Sei can also operate in this shallow water.

It may be possible to perform alternative installation by positioning a dynamic positioned (DP) pipelay vessel, e.g. Allseas' Lorelay in 17m waterdepth, approximately 5km away from the NGT pipeline target box. The DP vessel will then produce the pipeline from this position and the pipeline end will be towed to the target box by a suitable tug or it will be pulled in by a winch on a barge, located near the target box. When the pipeline head is positioned in the target box near NGT, the DP vessel continues pipeline installation on DP towards the target box near the N05A platform. It requires more work by Allseas to confirm whether this option can be executed, but they have **provisionally** priced it.

Survey will be performed by a 3rd party survey vessel. Pigging and pressure testing could be performed from a third party multicat or using a dedicated vessel such as Allseas' Calamity Jane.

6.2 Unburied Pipeline Installation Spread

The Tog Mor has a tensioner capacity of 100T, which is not sufficient to install a 20 inch schedule 60 pipeline, with 140mm concrete weight coating, in 26m waterdepth. The Tog Mor can install a 20 inch pipeline with 140mm CWC up to 17m waterdepth, at which point DP pipelay vessel Lorelay or Audacia can pick the pipeline up and continue installation towards the N05a location.

Van Oord's shallow water pipelay vessel Stingray has a tensioner capacity of 140T, which is likely to be sufficient to install the pipeline with 140mm concrete weight coating up to the maximum waterdepth of 26m. This will have to be confirmed by analyses. It must be noted that the Stingray is currently stored and has not been used for quite some time.

The Castoro Sei is a large semi-sub pipelay vessel operating on anchors, it has more than sufficient capacity to install a concrete coated 20 inch pipeline but it is large for our N05a pipeline and it is expected that it will not be priced attractively.

Due to the weight of the concrete coated pipeline it will not be possible to install it with a DP vessel in a stationary position as described above. For the cost estimate it has been assumed that an unburied pipeline will be installed by a combination of the Tog Mor and Lorelay installation vessels for shallow and deeper water sections respectively.

6.2 Buried Pipeline installation Spread

A buried pipeline with no- or maximum 40mm thick concrete weight coating can be installed completely from 8m water depth to 26m water depth by the Tog Mor, the Stingray or the Castoro Sei. Alternatively it may be possible to install this lighter pipeline with a DP pipelay vessel from a stationary position, as described in section 6.1. This will be substantially more cost efficient than installation with an anchor operated pipelay barge, due to much higher pipelay speed resulting in shorter duration.

To bury the pipeline Allseas would use a subcontractor's mass flow excavator operated from a multicat vessel. A picture of such equipment is given in appendix D.
It is unclear whether Van Oord and Saipem would use their own equipment to bury the pipeline or whether they would subcontract that work.

7.0 INSTALLATION COST COMPARISON

A cost comparison between buried pipeline installation and unburied pipeline installation is given below. As base case the Allseas provided prices have been used for the Tog Mor and Lorelay, since those are the most viable options. For the buried pipeline it may be possible to optimize the costs by installing the pipeline without concrete weight coating, this will be determined during detailed design. Please note that the costs below do not include tie-in spool installation.

	Buried Lorelay	**Buried Tog Mor**	**Unburied Tog Mor & Lorelay**	**Budget**
Materials	**€ 6,610,750**	**€ 6,610,750**	**€ 9,083,000**	**€ 6,465,263**
20 inch Line pipe + FBE coating	€ 4,673,250	€ 4,673,250	€ 4,673,250	
Concrete weight coating	€ 1,937,500	€ 1,937,500	€ 4,409,750	
Installation	**€ 12,680,000**	**€ 17,702,000**	**€ 17,148,000**	**€ 10,200,000**
PM & Engineering	€ 723,000	€ 723,000	€ 1,800,000	
Mob/demob + fixed costs	€ 3,266,000	€ 3,179,000	€ 5,400,000	€ 3,900,000
Pipeline installation	€ 5,393,000	€ 9,526,000	€ 6,300,000	€ 3,900,000
Survey	€ 1,570,000	€ 2,326,000	€ 2,326,000	€ 1,300,000
Trenching	€ 516,000	€ 516,000	€ 0	
Flooding/gauging and testing	€ 992,000	€ 992,000	€ 992,000	€ 1,100,000
Guard vessels	€ 150,000	€ 300,000	€ 225,000	
Northsea pilots	€ 70,000	€ 140,000	€ 105,000	
Total	**€ 19,290,750**	**€ 24,312,750**	**€ 26,231,000**	**€ 16,665,263**
Impact compared to budget	€ 2,625,487	€ 7,647,487	€ 9,565,737	

8.0 CONCLUSION

After evaluation of advantages and disadvantages of the buried and unburied pipeline options it has been concluded that a buried N05a gas export pipeline is the best option, based on the following:

- Unacceptable failure risk of an unburied pipeline by dragging anchors, fishing activities or sinking ships. An unburied pipeline does not fulfil the failure risk requirements of NEN3656. To reduce the failure risk in accordance with NEN3656 the pipeline must be buried minimum 0.8m deep.
- An unburied pipeline with 140mm concrete weight coating is not stable in the 10000 year storm conditions, it moves considerably even when 25% natural embedment is taken into account. The required concrete weight coating thickness of 240mm to make an unburied pipeline stable is thicker than the 150mm maximum thickness that can be fabricated. A buried pipeline is stable in the 10000 year storm conditions.
- Better pipeline install-ability. Due to the lower weight of the pipeline without concrete weight coating it can be installed by several shallow water pipelay vessels. For a heavy concrete weight coated pipeline the available installation vessels are limited and may not be available for the desired installation window. Alternatively it may be possible to install the lighter pipeline by a DP operated pipelay barge, which will be more cost effective.
- Lower overall costs. Concrete weight coating of 140mm thickness is more expensive than pipeline trenching. Moreover a larger number of installation vessels are available to install a pipeline without weight coating, which will result in more competition and better prices.

APPENDIX A DATA SHEET PIPELINE INSTALLATION VESSEL TOG MOR

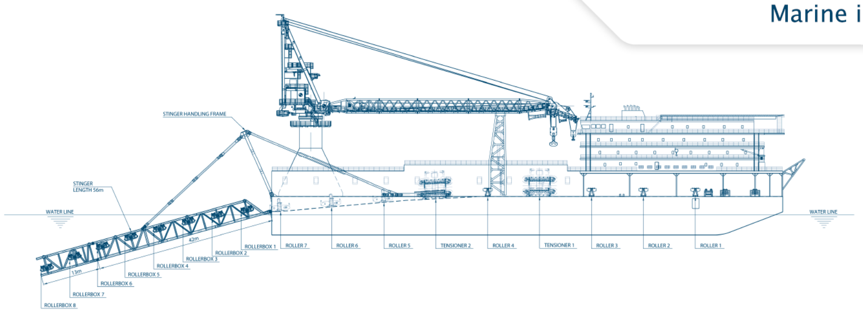
TOG MOR
Vessel specifications

Length overall (incl. stinger)	154 m (505 ft)
Length overall (excl. stinger)	111 m (364 ft)
Breadth	27 m (89 ft)
Depth to main deck	6 m (20 ft)
Operating draught	2 m (7 ft)
Mooring system	Flipper Delta anchors, 10 points: Forward: 4 x 10 t (20 kips) and 2 x 8.5 t (20 kips) Aft: 4 x 7 t (15 kips)
Total installed power	3750 kW
Accomodation	144 persons
Helideck	Maximum take-off weight 11.1 t, suitable for Sikorsky S-92 and Puma 100 helicopters
Deck cranes	Main crane of 300 t (660 kips) at 17 m (55 ft) main hoist Crawler crane of 79 t (170 kips) at 8 m (26 ft) main hoist
Work stations	3 (single joint) welding stations, 1 NDT station and 1 coating stations
Installed tension capacity	1 x 100 t
Pipe cargo capacity on main deck	10 t/m²
Pipe diameters	From 2" to 60" OD
Clear deck space	1000 m²
Classifications	LR A1 Barge, crane pontoon
Port of registry	Valletta

APPENDIX B DATA SHEET PIPELINE INSTALLATION VESSEL STINGRAY

Principal particulars

Van Oord
Marine ingenuity



Stingray

Name	Stingray	
Type	Shallow water pipe lay barge	
Classification	ABS, ✠ A1 Barge	
Year of construction	2012	
Dimensions	Length overall	120 m (394 ft)
	Breadth overall	40.1 m (132 ft)
	Moulded depth	9 m (29.5 ft)
	Design draft	5 m (16.4 ft)
Allowable deck load	12.5 t/m^2	
Free deck area	2,000 m^2	
Working depth	4.5 - 100 m (14.9 - 328 ft) (depending on pipeline parameter)	
Stinger	Fixed, 55 m (180 ft) total length in two sections, ABS certified	
Accomodation	8 x 1 Berth cabins	8 men
	14 x 2 Berth cabins	28 men
	66 x 4 Berth cabins	264 men
	Total	300 men
	All cabins have toilet/shower facilities	
Recreation rooms	2 ea complete (for clients and crew)	
	Complete with TV/Video Room	
Gym	1 ea	
Messroom	150 men seating	
Office/ Conference room	12 ea	
Main crane	Liebherr model BOS 14000-500 D Litronic	
Main hook capacity	500 t @ 18 m radius (optional 2,000 t)	
Auxiliary hook capacity	50 t @ 59 m radius	
Maximum outreach main hook	54 m (177.2 ft)	
Maximum outreach auxiliary hook	9.3 m (30.5 ft)	
Store cranes	2 x Palfinger PTM900 telescopic boom Marine Crane; SWL 2.7t @ 20 m radius	
Crawler crane	1 x 250 t, Kobelko, 2500 CE, 42 m boom	
Davits (optional)	6 x 50 t	
Pipe lay capacities	Pipe OD 6 - 60 inch including CWC coating	
	Tensioners 2 x 70 t capacity (make: PH Hydraulics)	
	A&R Winch 150 t capacity (make: PH Hydraulics)	
Welding stations	3 nos.	
NDT/repair station	1 no.	
Field joint stations	3 nos.	
Mooring system	Anchors	10 x 12 t Flipper Delta
	Anchor winches (electric)	10 x 150 t single drum
	Mooring lines	10 x 52 mm Ø x 1,500 m

Helideck	CAP 437, suitable for S-92 Sikorsky helicopter	
Tank capacities	SWB/F.W. tank (non-potable)	14,000 m^3 approx.
	F.W. tank (potable)	2,000 m^3 approx.
	F.O. tank	1,900 m^3 approx.
	Dirty oil tank	50 m^3 approx.
	Bilge holding tank	70 m^3 approx.
	Hydraulic oil storage tank	10 m^3 approx.
	Lubrication oil storage tank	10 m^3 approx.
	Sewage tank	120 m^3 approx.
Machinery	Main generators	6 x 1,230 kW, 440V, 60HZ 3 Phase
Emergency diesel generator	1 x 150 kW	
Air compressor	2 x 850 m^3/hr @ 10 bar	
Fresh water makers (RO)	2 x 75 t/day	
Sewage treatment plant	2 nos. with total capacity for 300 persons	
Pumps	Ballast pump	3 nos, 1,000 m^3/hr at 30 m head
	F.O. transfer pump	2 nos, 45 m^3/hr at 45 m head
	Fresh water transfer pump	2 nos, 120 m^3/hr at 35 m head
	Dirty oil pump	3 m^3/hr at 30 m head
	Bilge pump	2 nos, 30 m^3/hr at 25 m head
	Fire & GS pump	2 nos, 130 m^3/hr at 80 m head
	Emergency fire pump	75 m^3/hr at 65 m head
Safety Equipment	2 x Foam monitor on helideck	
	2 x Monitor on A-deck	
	MES System 2 x 300 people	
	1 Rescue boat with single arm davit	
	1 Fast rescue boat	
	Life jackets: 200% coverage of the total maximum onboard	
Communications and navigation system	Radio system, email, fax, internet, satellite navigation system, DGPS, VSAT system	

Contact

Van Oord Offshore
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E area.off@vanoord.com
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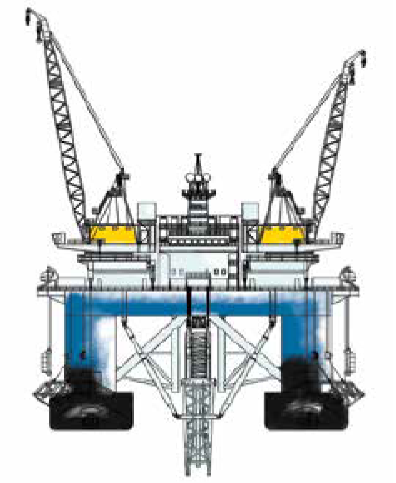
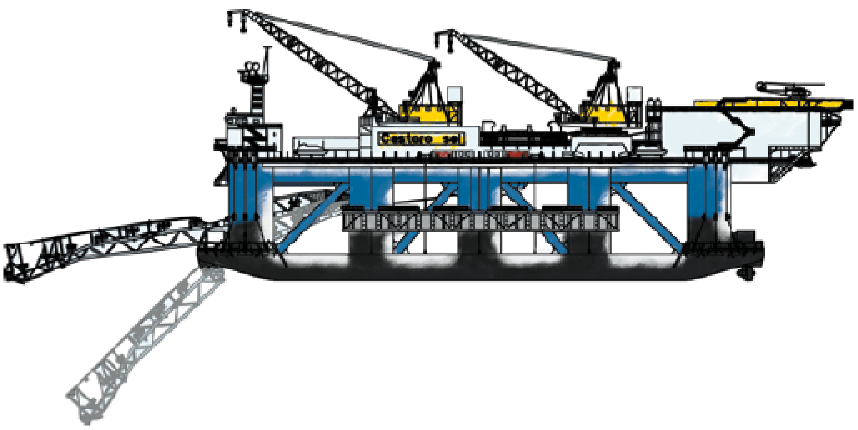
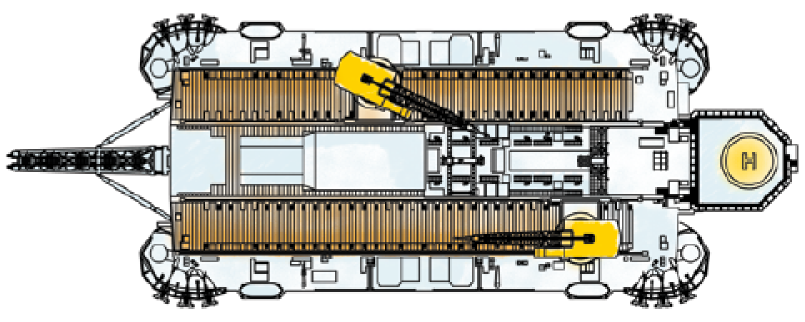
November 2013

APPENDIX C DATA SHEET PIPELINE VESSEL CASTORO SEI







HULL TYPE
Column stabilised semi-submersible

VESSEL FEATURES

Length overall excluding ramps	152.0 m
Breadth overall	70.5 m
Depth to main deck	29.8 m
Transit draft	9.5 m
Operating draft (typical)	14.0 m
Survival draft	12.5 m
Dedicated pipe storage space	1,195 sq.m
Additional deck space	1,525 sq.m
Deck load	3,600 tonnes

CLASSIFICATION
American Bureau of Shipping

COMPLIANCE
NMA, HSE

PROPULSION / POSITIONING SYSTEM
Four 37 tonne Azimuthal thrusters
Twelve 25 tonne anchors
Twelve 124 tonne anchor winches
3,000 m anchor wire on each winch of 76 mm

PIPELAY EQUIPMENT
2 Rotating gantry cranes 134 tonnes capacity
Longitudinal conveyor, gantry transfer conveyors, line-up station
Three 130 tonne pipe tensioners
Fixed ramp, articulated ramp, mini ramp extension
Bevelling stations
Double jointing system
Welding stations utilising a semi automatic system
X-ray or AUT equipped NDT stations
Field joint coating system
Abandonment & recovery winch (400 tonnes)
Piggyback lay welding line facility
Dual-lay welding line and ramp

HELIDECK
Suitable for helicopters up to and including the Sikorsky S61N type

NAVIGATION & COMMUNICATIONS
Fully equipped radio room GMDSS
Satellite communications & TV
2 ARPA radars
GPS / DGPS navigation & positioning
Echosounder

POWER GENERATION

6 Main generators	20.5 Mw total
1 Emergency generator	800 Kw

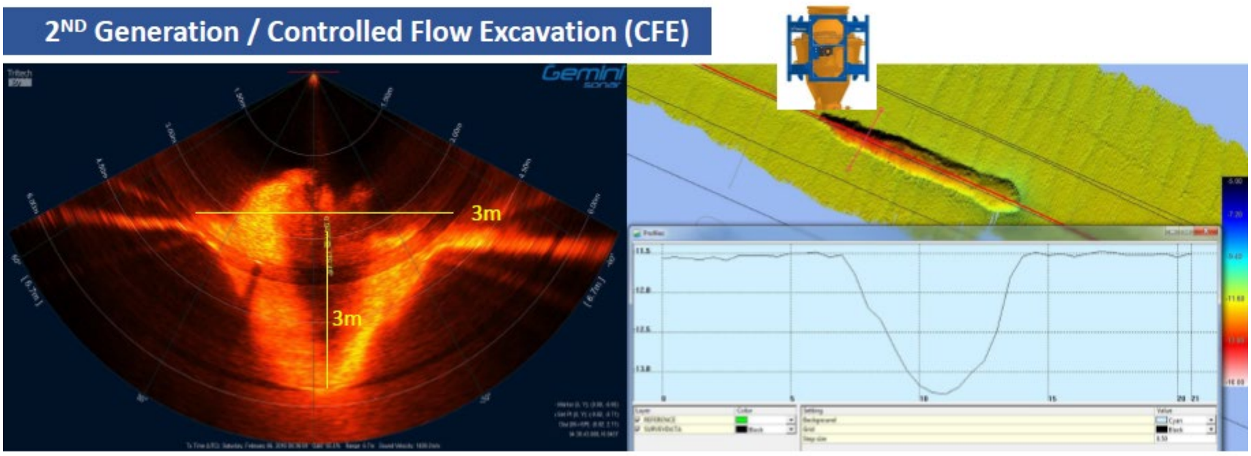
BUNKER CAPACITY

Ballast capacity	11,518 cu.m
Lube oil capacity	138 cu.m
Fuel oil capacity	3,123 cu.m
Potable water capacity	1,000 cu.m

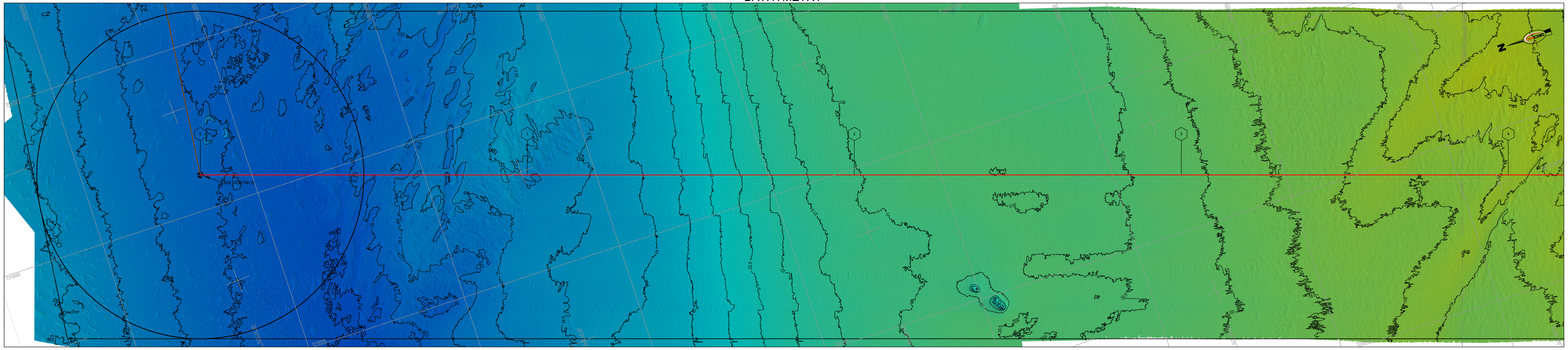
Fresh water generators
180 tonnes / day

CREW FACILITIES
Accommodation for 347 people
Client offices
Conference rooms
Hospital
Gymnasium
Galley mess room
Coffee bar
Cinema
Recreation rooms
Satellite television

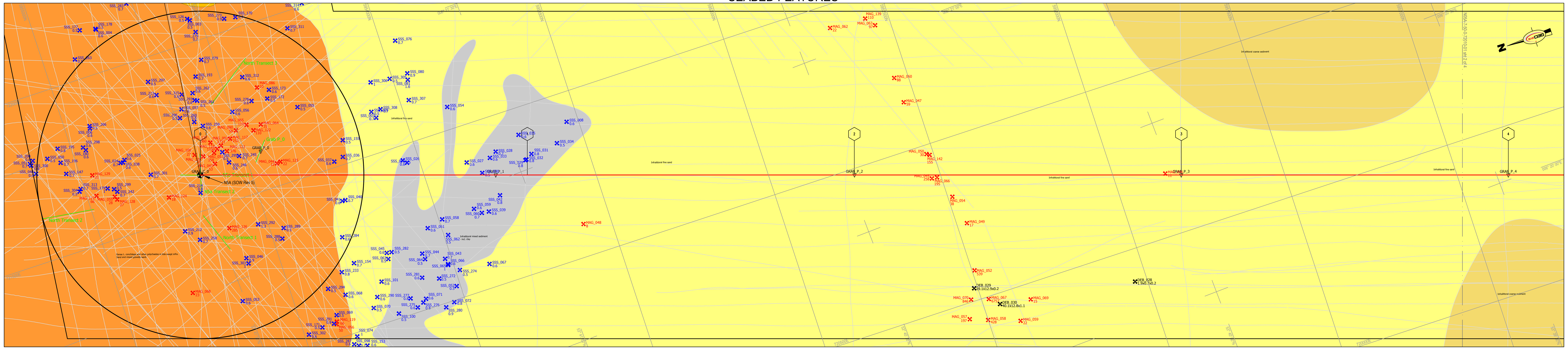
APPENDIX D MASS FLOW EXCAVATOR EXAMPLE



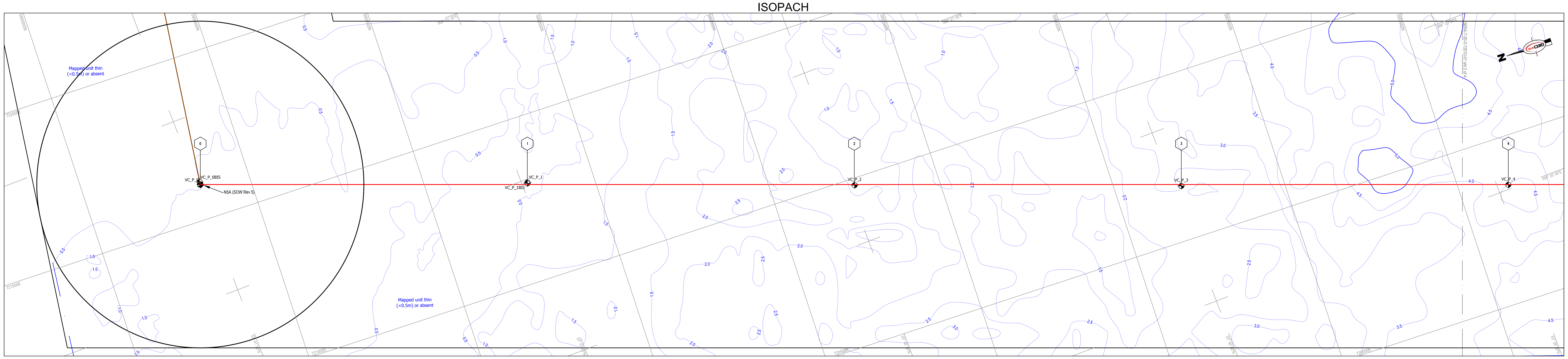
BATHYMETRY



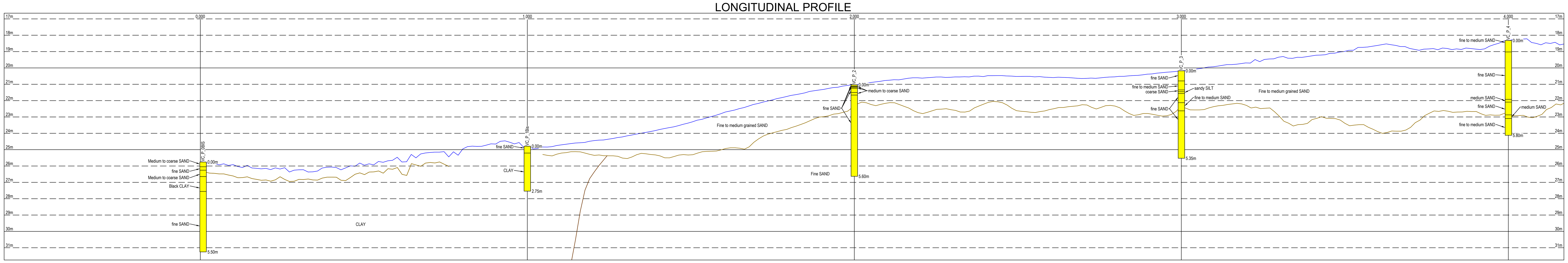
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

Kilometer point

Theoretical pipeline position

Chart match lines

Survey Area (500m at each side of proposed pipeline/cable)

Proposed pipeline route

Proposed cable route

Natura 2000

Cables

Pipelines

500m zone

Proposed new location for N5A platform

Internal cables Riffgat

Monopile location Riffgat

Graticule grid

U.T.M. grid

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals

Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m

Height (m)

SEABED FEATERS:

Vessel track

Linear debris

Camera transects

SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m

MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT

DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)

GRAB_P_12 — Position of grab sample

Infralittoral fine sand (A5.23)

Infralittoral coarse sediment (A5.13)

Infralittoral mixed sediment (A5.43) - no clay

Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)

Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

1.0 contour at 0.5 metre intervals

Data extents

Shallow gas

VC_C_4 — Position of vibrocore

LONGITUDINAL PROFILE:

Seabed

Base surfical sand

Clay

4.000 — Kilometer point

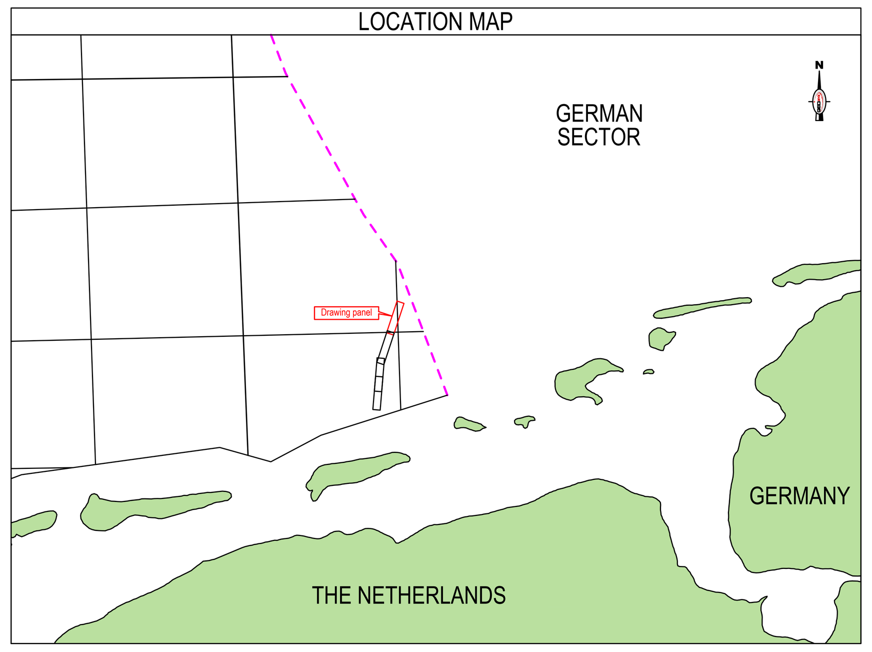
VC_C_1 — Name of vibrocore

0.00m

4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

SURVEY SOFTWARE

Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
Semi-major axis:	a = 6378388.00m
Semi-minor axis:	b = 6356911.95m
First eccentricity squared:	e2 = 0.006723
Inverse flattening:	1/f = 297.000
EPSG code:	23031
Projection:	UTM31N
Central meridian:	03° east
Latitude of origin:	0°
False easting:	500000.00m
False northing:	0.00m
Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):

Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO NGT HT ROUTE

Pipeline route

KP 0.000 to 4.170

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 001/004 | Scale: 1/5000 | LAT

Drawing made by:

GEOXYZ OFFSHORE
2 Route D'Arlon
Windhof Business center block A
L-8388 WINDHOF
Luxembourg

Client:

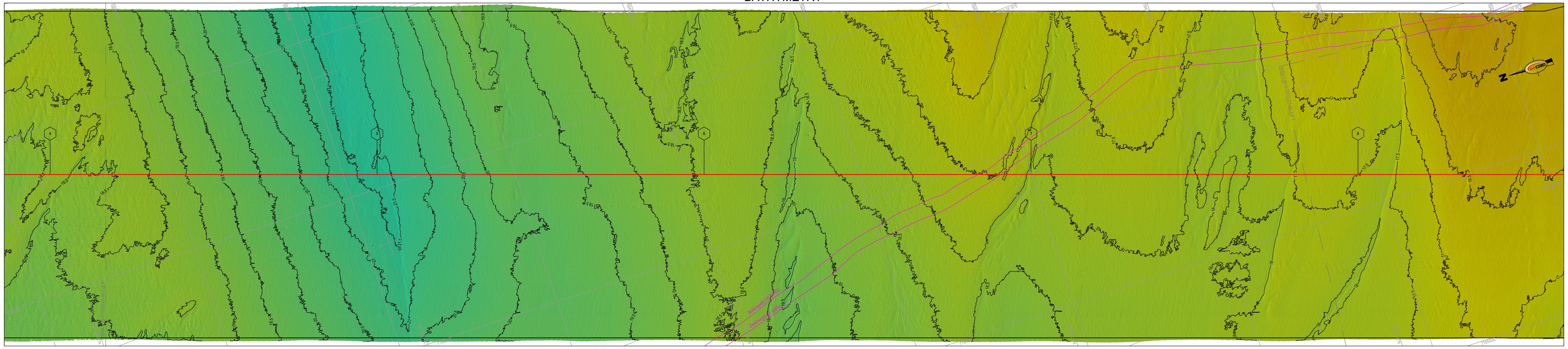
Oranje-Nassau Energie B.V.
UNStudio, 7th floor
Parnassusweg 815
1082 LZ Amsterdam (The Netherlands)

Tel: +31 20 535 41 00
Fax: +31 20 535 41 22

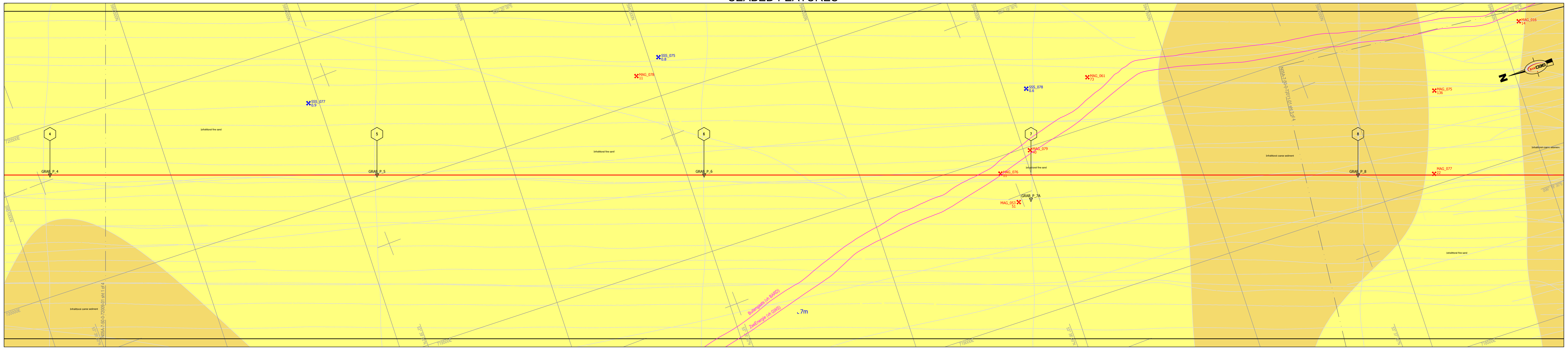
Issue no:	Date:	Description:	Drawn:	Checked:
1	12/06/2019	Second internal review	STH	RSP/TDB
2	15/07/2019	Issued for use	STH	RSP/TDB
3	05/09/2019	Client remarks	STH	RSP/TDB
4	01/10/2019	Client remarks	STH	RSP/TDB

Planname:	LU0022H-553_DR-007_PR_1-4_v4.0	Project ref:	N05A-7-50-0-72009-01 sht 1 of 4

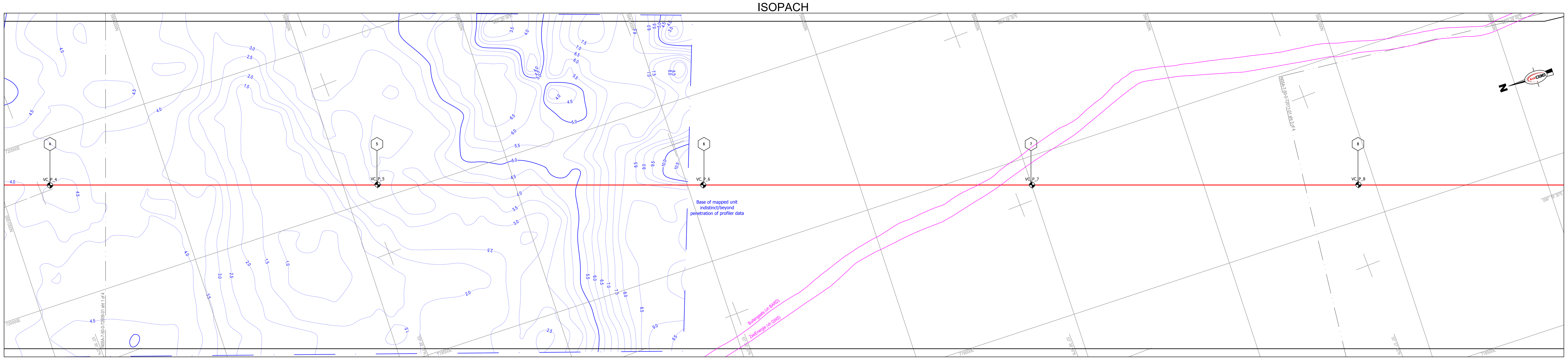
BATHYMETRY



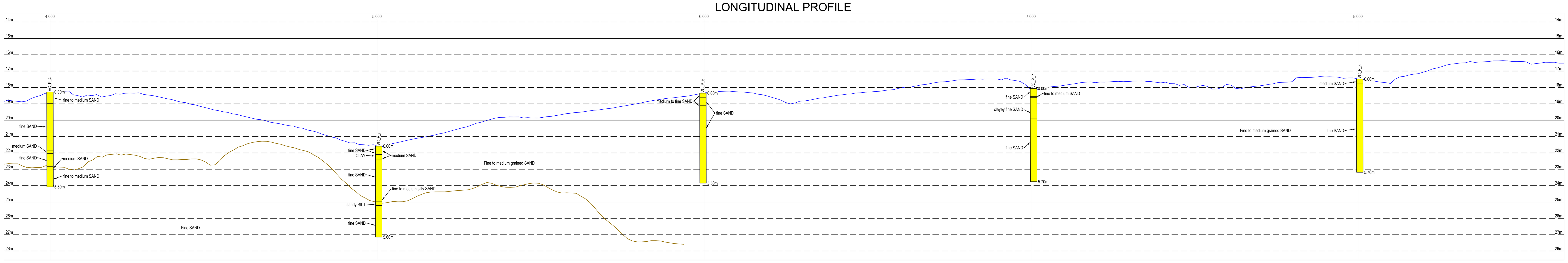
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

Kilometer point

Theoretical pipeline position

Chart match lines

Survey Area (500m at each side of proposed pipeline/cable)

Proposed pipeline route

Proposed cable route

Natura 2000

Cables

Pipelines

500m zone

Proposed new location for N5A platform

Internal cables Riffgat

Monopile location Riffgat

Graticule grid

U.T.M. grid

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals

Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m Height (m)

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Vessel track

Linear debris

Camera transects

SSS_266 0.8 — Object ID, SSS contact/object: Unit value: m

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Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

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2. The mapped unit is expected to comprise dense SAND

1.0 contour at 0.5 metre intervals

Data extents

Shallow gas

VC_C_4 — Position of vibrocore

LONGITUDINAL PROFILE:

Seabed

Base surfical sand

Clay

4.000 — Kilometer point

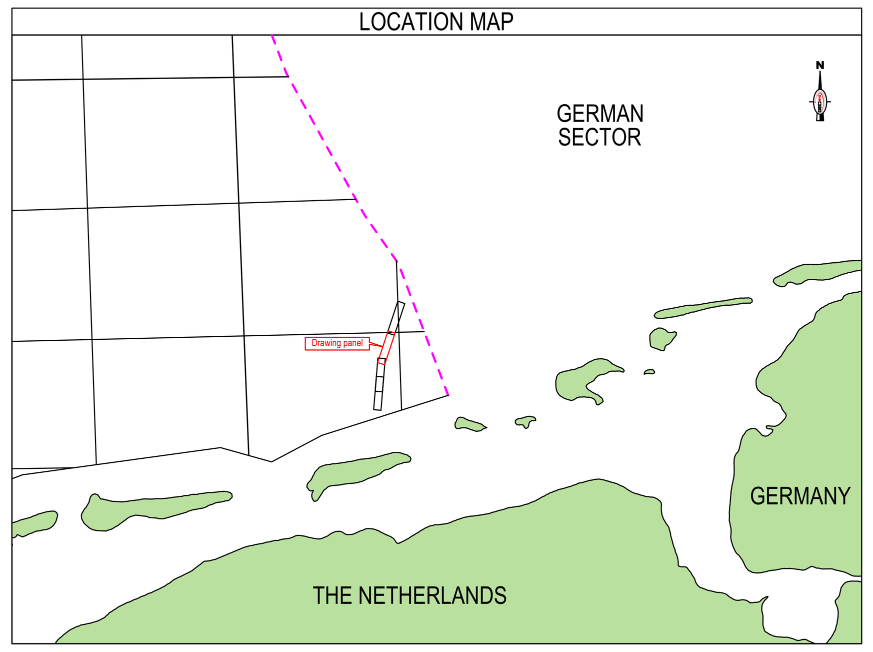
VC_C_1 — Name of vibrocore

0.00m

4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
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False easting:	500000.00m
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Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

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Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):

Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO NGT HT ROUTE

Pipeline route

KP 3.860 to 8.630

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 002/004	Scale: 1/5000	LAT

Drawing made by:

GEOXYZ OFFSHORE
2 Route D'Arlon
Windhof Business center block A
L-8388 WINDHOF
Luxembourg

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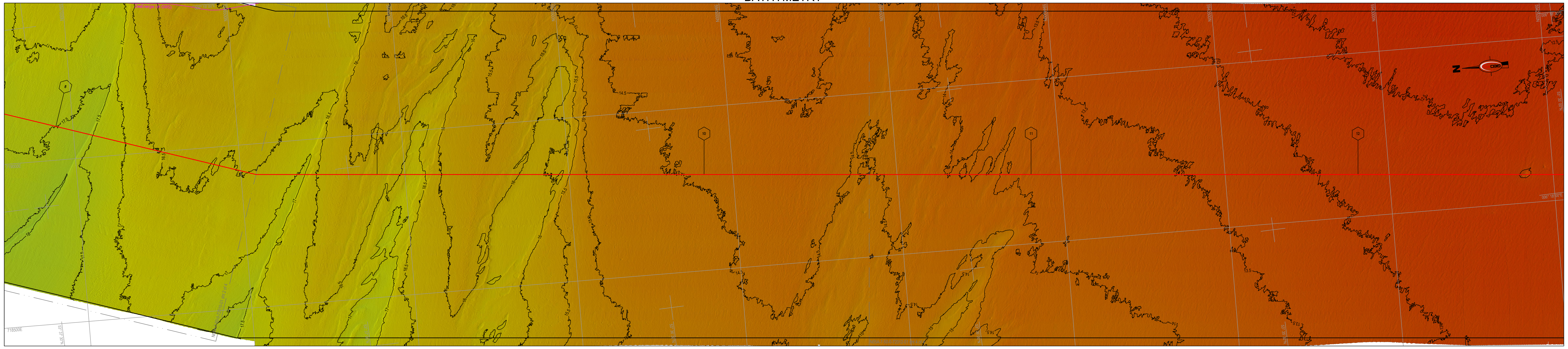
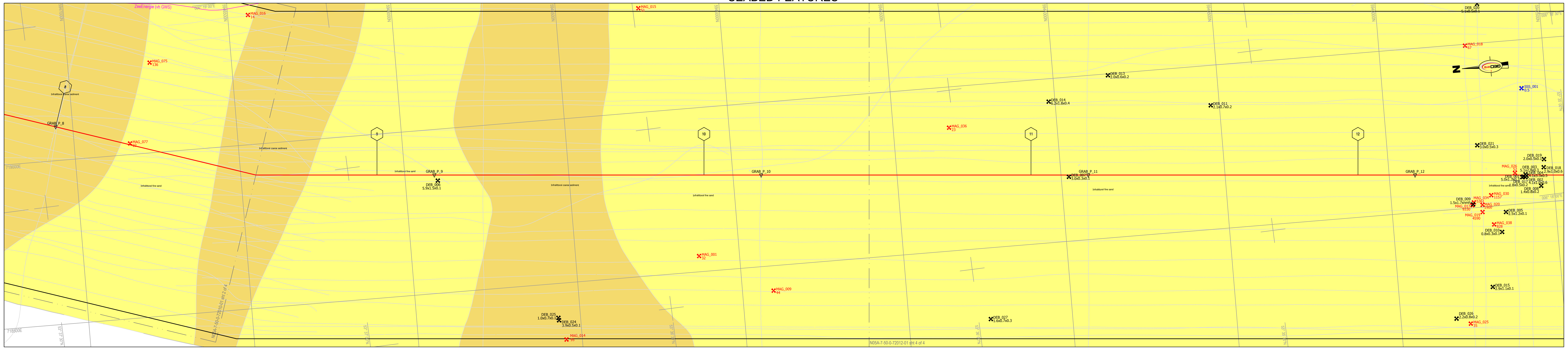
Planname:	LU0022H-553_DR-008_PR_2-4_v4.0	Project ref:	N05A-7-50-0-72010-01 sht 2 of 4

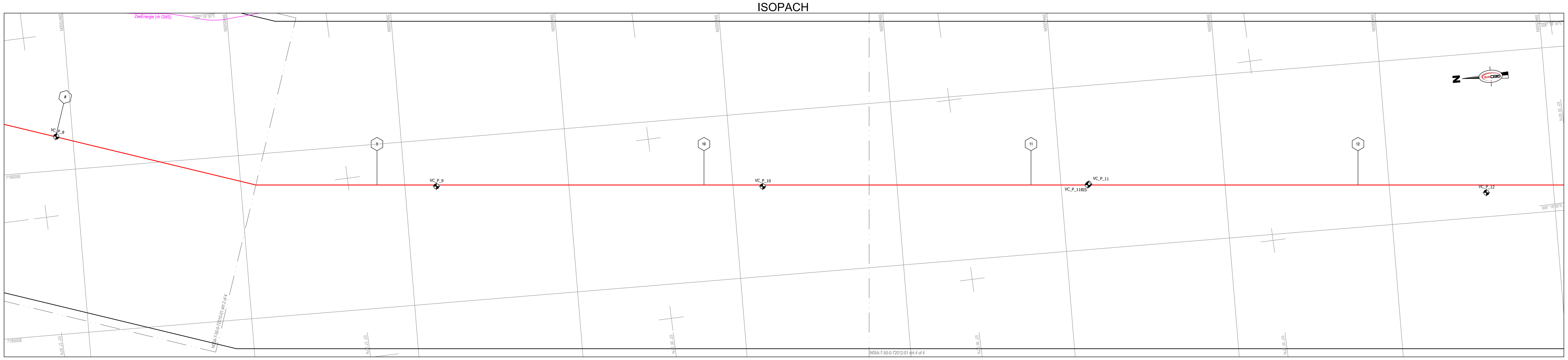
BATHYMETRY



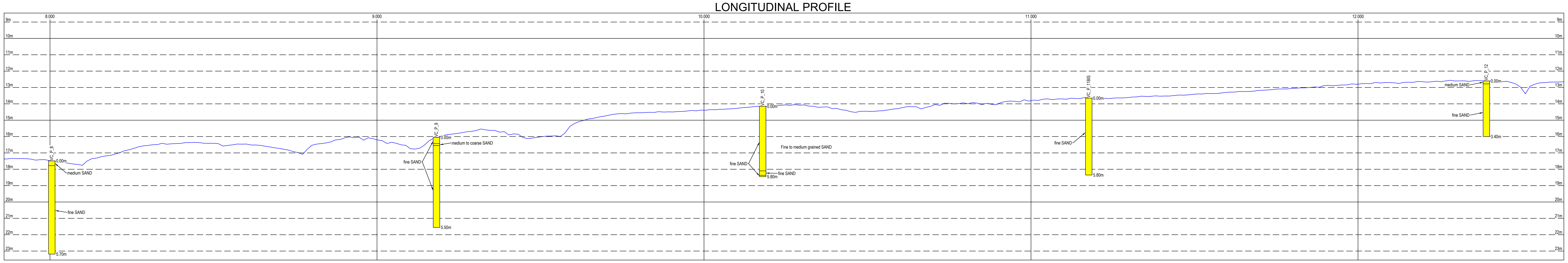
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

- Kilometer point
- Theoretical pipeline position
- Chart match lines
- Survey Area (500m at each side of proposed pipeline/cable)
- Proposed pipeline route
- Proposed cable route
- Natura 2000
- Cables
- Pipelines
- 500m zone
- Proposed new location for N5A platform
- Internal cables Riffgat
- Monopile location Riffgat
- Graticule grid
- U.T.M. grid

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All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals
Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m Height (m)

SEABED FEATERS:

- Vessel track
- Linear debris
- Camera transects
- SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m
- MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT
- DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)
- GRAB_P_12 — Position of grab sample

- Infralittoral fine sand (A5.23)
- Infralittoral coarse sediment (A5.13)
- Infralittoral mixed sediment (A5.43) - no clay
- Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)
- Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

- 1.0 contour at 0.5 metre intervals
- Data extents
- Shallow gas
- VC_C_4 — Position of vibrocore

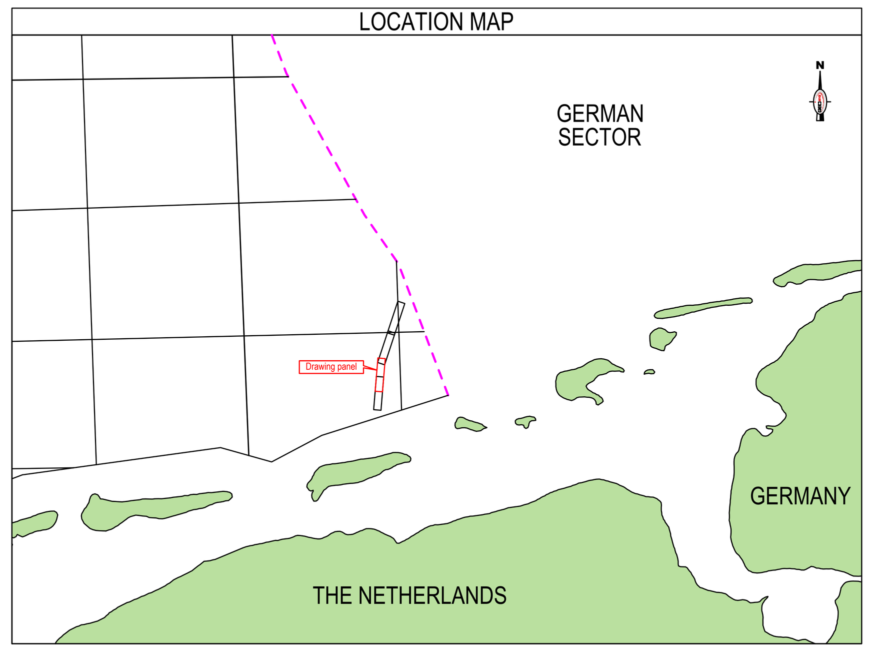
LONGITUDINAL PROFILE:

- Seabed
- Base surfical sand
- Clay
- 4.000 Kilometer point

VC_C_1 — Name of vibrocore
0.00m
4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

SURVEY SOFTWARE

Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
Semi-major axis:	a = 6378388.00m
Semi-minor axis:	b = 6356911.95m
First eccentricity squared:	e2 = 0.006723
Inverse flattening:	1/f = 297.000
EPSG code:	23031
Projection:	UTM31N
Central meridian:	03° east
Latitude of origin:	0°
False easting:	500000.00m
False northing:	0.00m
Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):

Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO NGT HT ROUTE

Pipeline route

KP 7.860 to 12.630

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 003/004 | Scale: 1/5000 | LAT

Drawing made by:

GEOXYZ OFFSHORE
2 Route D'Arlon
Windhof Business center block A
L-8388 WINDHOF
Luxembourg

Client:

Oranje-Nassau Energie B.V.
UNStudio, 7th floor
Parnassusweg 815
1082 LZ Amsterdam (The Netherlands)

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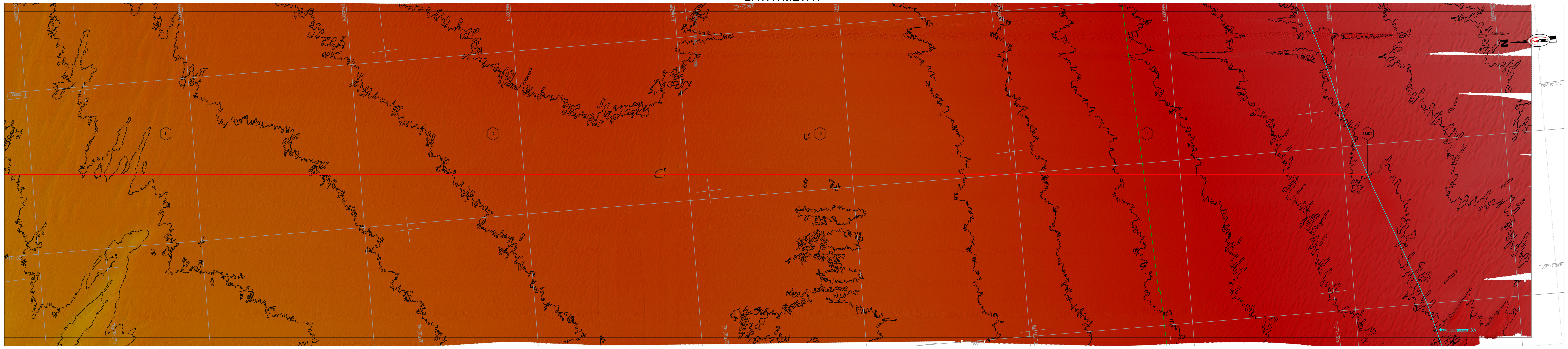
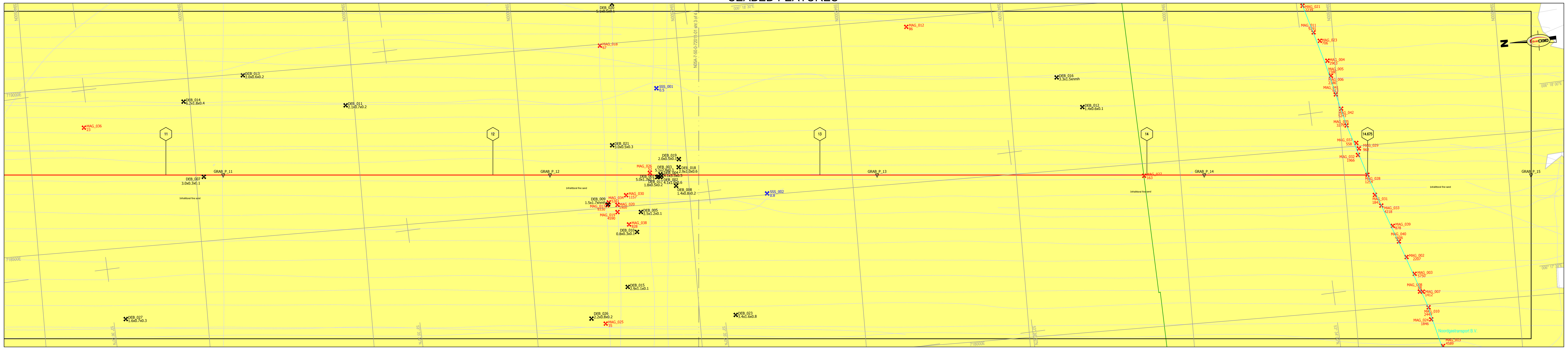
Planname:	LU0022H-553_DR-009_PR_3-4_v4.0	Project ref:	N05A-7-50-0-72011-01 sht 3 of 4

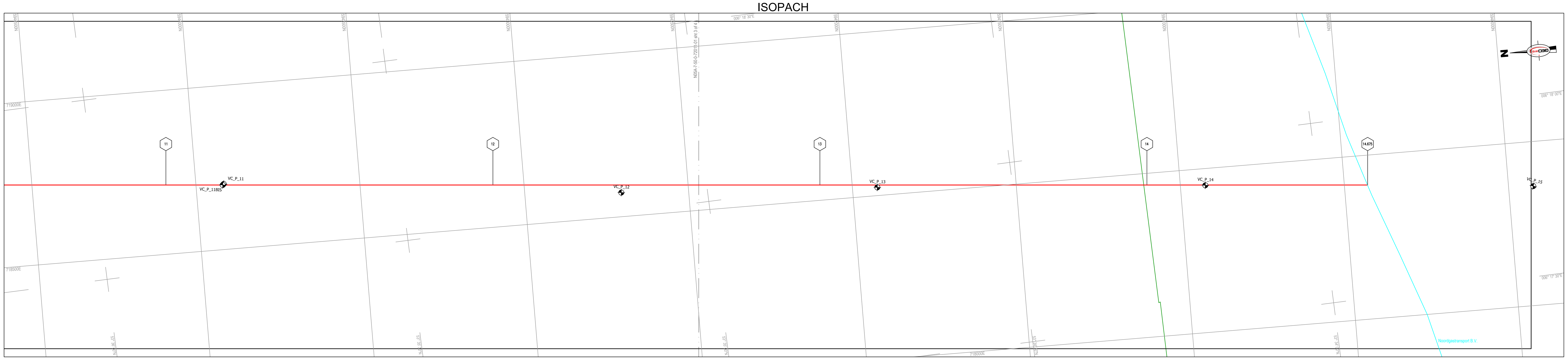
BATHYMETRY



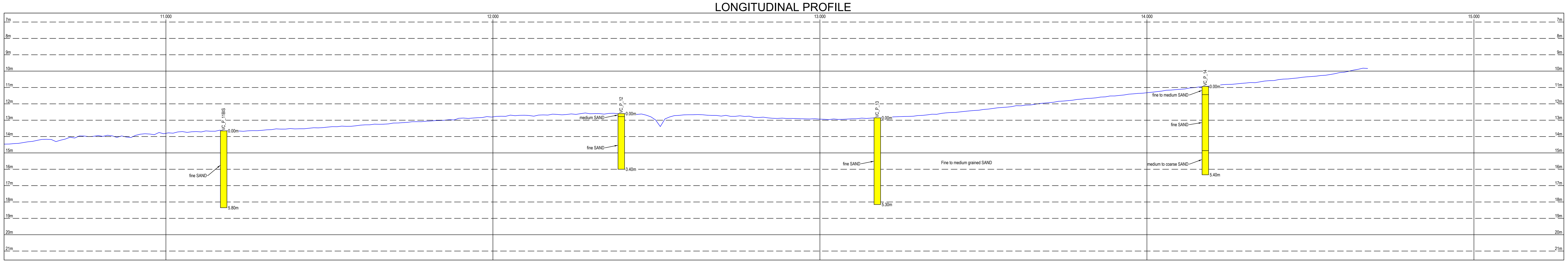
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

- Kilometer point
- Theoretical pipeline position
- Chart match lines
- Survey Area (500m at each side of proposed pipeline/cable)
- Proposed pipeline route
- Proposed cable route
- Natura 2000
- Cables
- Pipelines
- 500m zone
- Proposed new location for N5A platform
- Internal cables Riffgat
- Monopile location Riffgat
- Graticule grid
- U.T.M. grid

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals
Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m Height (m)

SEABED FEATERS:

- Vessel track
- Linear debris
- Camera transects
- SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m
- MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT
- DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)
- GRAB_P_12 — Position of grab sample

- Infralittoral fine sand (A5.23)
- Infralittoral coarse sediment (A5.13)
- Infralittoral mixed sediment (A5.43) - no clay
- Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)
- Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

- 1.0 contour at 0.5 metre intervals
- Data extents
- Shallow gas
- VC_C_4 Position of vibrocore

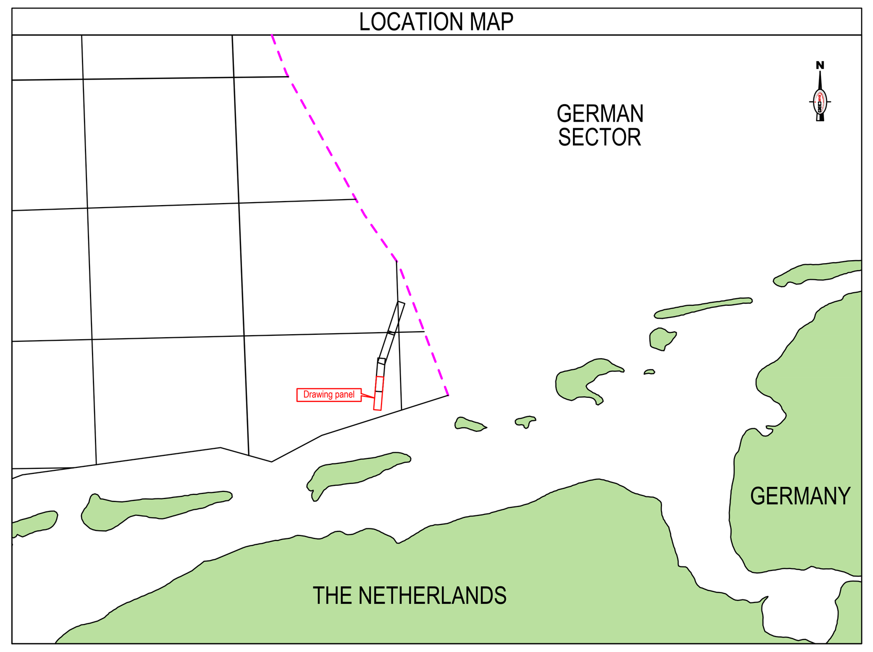
LONGITUDINAL PROFILE:

- Seabed
- Base surfical sand
- Clay
- 4.000 Kilometer point

VC_C_1 — Name of vibrocore
0.00m
4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



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N5A development - pipeline route & platform area survey

N5A TO NGT HT ROUTE

Pipeline route

KP 10.505 to 14.675

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 004/004 | Scale: 1/5000 | LAT

Drawing made by:

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Planname:	LU0022H-553_DR-010_PR_4-4_v4.0	Project ref:	N05A-7-50-0-72012-01 sht 4 of 4

N05-A Pipeline design

Risk assessment & dropped object analysis

DOCUMENT NUMBER:

N05A-7-10-0-70030-01

Rev.	Date	Description	Originator	Checker	Approver
01	02-01-2020	For Comments			
02	24-01-2020	For Approval			
03	12-10-2020	Extra CWC options			

Client

ONE-Dyas B.V.

Project

N05-A Pipeline Design

Document

Risk assessment & dropped object analysis

Project number	19018
Document number	N05A-7-10-0-70030-01
Client document number	N05A-7-10-0-70030-01
Revision	03
Date	12-10-2020

Revision History

Revision	Description
01	For Client Comments
02	Client comments incorporated
03	Extra CWC options

Revision Status

Revision	Description	Issue date	Prepared	Checked	Enersea approval	Client approval
01	For Client Comments	02-01-2020				
02	For Client Approval	24-01-2020				
03	Extra CWC options	12-10-2020				

Table of content

1. Introduction

1.1. Project Introduction

One-Dyas plans to develop a successfully drilled well in block N05-A of the North Sea Dutch Continental Shelf. More wells will be drilled at this location through the same jacket. It is planned to develop the wells by installing a platform and a gas export pipeline with a connection to the NGT pipeline @KP142.1. Approximate length of the pipeline is 14.7 km.

In addition, a power cable will be installed from the Riffgat Windpark to the N05-A platform.

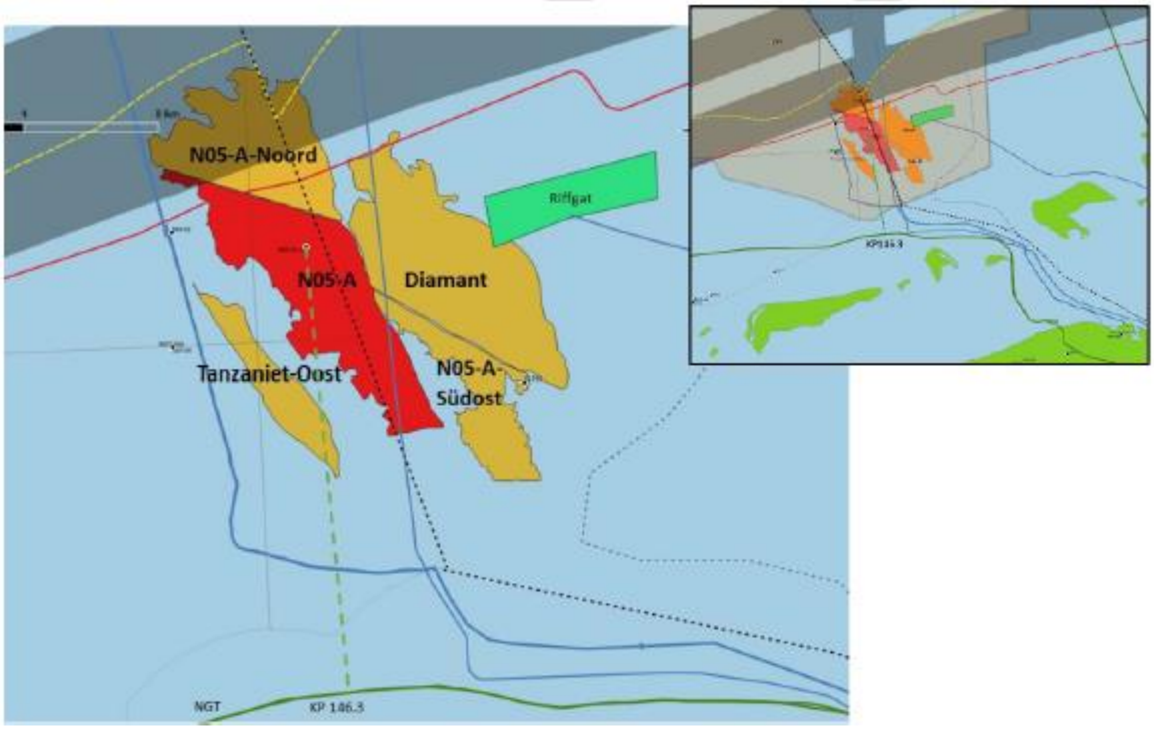


Figure 1, N05A Field layout

1.2. Purpose and scope of Document

This document fulfils the requirements for risk assessments for the 20” pipeline from the N05-A platform to the tie-in location on the NGT, and to comply with Dutch codes (ref [3]) and regulations. The report contains the outcome of the RIE workshop. The risk register is captured in Appendix B.

The quantitative risk assessment for the typical subsea Third Party threats are based on the general practice of industry, engineering judgements and AIS shipping data has been applied to determine the ships density.

The analyses presented, both contain the buried pipeline case and the un-buried pipeline case.

1.3. System of Units

All dimensions and calculations applied are based on the International System of Units (SI) unless noted otherwise.

1.4. Abbreviations

AIS	Automatic Identification System
ALARP	As Low As Practical Achievable
BoD	Basis of Design
CWC	Concrete Weight Coating
DWT	Dead Weight Tonnage
DFI	Design Fabrication and Installation
DNV	Det Norsk Veritas
DNVGL	Det Norsk Veritas &Germanisher Lloyds
DWT	Dead Weight Tonnage
ESDV	Emergency shutdown valve
NEN	Nederlands Normalisatie-Instituut
NGT	Noord-Gas-Transport B.V.
PIMS	Pipeline Integrity management System
RIE	Risk Inventarisation and Evaluation
ToP	Top of Pipe
TPI	Third Party Interference

1.5. References

[1] Overheidsbeleid inzake de aanleg van offshore pijpleidingen voor het transport van olie en/of gas, letter to NOGEPA from the Dutch Ministery of Economic Affairs, dated 03 November 1987;

[2] Risk analyses and burial requirements for Dutch Continental Shelf pipelines, D.Schaap a.o., 1987;

[3] Eisen voor Stalen Transportleidingsystemen, NEN 3656 (Requirement for Steel Pipeline Transportation Systems);

[4] Veiligheidsanalyse voor zeeleidingen, Rijkswaterstaat Directie Noordzee;

[5] -;

[6] Monitoring-nautische-veiligheid-2013-noordzee;

[7] Beleidsnota Scheepvaartverkeer Noordzee "Op Koers", no 17408-26, Ministerie van Verkeer en Waterstaat, Januari 1987;

[8] Snelle reparatie Unocal-pijp volgens het boekje verlopen, Offshore Visie Magazine, Juni 1988;

[9] Mooring Anchors, The society of Naval Architects and Marine Engineers Transactions, Vol 67, 1959;

[10] Lloyd's "Register of Ships";

[11] DNV RP-F107 - Risk Assessment of Pipeline Protection - October 2010;

[12] DNV-RP-C204 – Design against accidental loads- November 2014;

[13] DNV-RP-F111 (2010)- Interference between trawl gear and pipelines;

[14] N05A-1-10-0-10001-01 FEED BOD platform facility;

[15] Marin Study, platform collision N05A, 32287-1-MO-rev0, November 2019;

[16] Geo XYZ, Surveys, 2019 LU0022H-553-RR-04-2.1, LU0022H-553-RR-05-1.1, LU0022H-553-RR-02;

[17] N05A-7-51-0-72510-01-03 - Overall field layout drawing;

[18] N05A-7-10-0-70031-01-01 – Route Selection Report;

2. Summary

This report presents the results of the pipeline risk assessments, for the export pipeline connecting the future ONE-Dyas platform N05A to NGT. Due to shipping traffic along the Southern shipping lanes and inbound and outbound traffic of the Eems-Dollard ports, the ship density in the whole area is high.

The pipeline Third Party shipping threats associated with high ship density, like dropped and dragging anchors, require additional measures to protect the pipeline and spools.

A pipeline RIE workshop was held on 3rd December 2019 and the following list contain in brief the outcome and highlights. Reference is also made to appendix A and B.

- Installation threats, due to installation, trenching and tie-in feasibilities;
- Third Party threats. Common subsea pipeline threats as dropped objects, dropped and dragging anchors and fishing gear impact;
- Natural hazards, related to on-bottom stability;

In this report the subsea pipeline third party threats are analysed in detail.

The dropped and dragging anchors are the most dominant threat. Table 1 shows the required minimal cover depth and probability of unacceptable damage per year per km of pipeline, as a function of ship traffic densities along the route and the applied CWC.

Table 1 Overview Pipeline leak probability (dropped and dragging anchors)

KP section	Ship density /1000 km^2	No CWC		40 mm CWC		140 mm CWC	
		Cover ToP [m]	Probalility [10^{-6}]	Cover ToP [m]	Probalility [10^{-6}]	Cover ToP [m]	Probalility [10^{-6}]
0.0 - 2.7	45	0.7	0.97	0.6	0.97	0.5	0.90
2.7 - 8.0	15	0.0	0.74	0.0	0.54	0.0	0.52
8.0 - 12.7	45	0.7	0.97	0.6	0.97	0.5	0.90
12.7 – 14.7	27	0.3	0.89	0.0	0.97	0.0	0.93

*Noe: calculated cover heights are excluding any potential natural sea bottom variations which might occur over the operational lifetime.

Within the shipping lane and for a pipeline without CWC, the pipeline Top of Pipe cover should be 0.7 m, to meet the acceptable risk level ($\leq 1.00 \cdot 10^{-6}$ per year per km of pipeline). The minimum cover depth for shipping lane or anchor zone is 0.6 m when 40 mm of CWC is considered, and 0.5m when 140 mm of CWC is applied. In lower density traffic zones, pipeline burial may not be required if a CWC is applied.

The determined cover depth for 140mm CWC in the shipping lane considers an update to NEN 3656, expected to be in effect by the time of pipeline installation, where the cover depth in a shipping lane is based on a risk assessment instead of the minimum requirement of 0.6m cover in the 2015 edition.

Fish gear interference for pipe diameters larger than 400 mm is negligible, according to NEN 3656 Section 9.4.2.6. Sinking ships are regarded as low risk due to the low probability of occurring in the vicinity of the pipeline.

The risk of dropped objects near the platform is fully mitigated with a rock berm height on top of pipe of 0.65 m. This risk is analyzed in section 8.

3. Dutch Authority Safety Criteria

The policy with regard to safety criteria for offshore pipelines is laid down in [1], effective 1987 and [3].

The Dutch Authorities require a minimum soil cover of 0.2 [m] for pipelines with a diameter smaller than 16-inch based on the maximum penetration depth of trawl gear into the sea bottom, consequently avoiding any contact between fishing gear and offshore pipelines. For areas denoted as shipping routes and anchor drop areas, a minimum cover depth of 0,6 [m] is required according to the 2015 edition in NEN 3656. In an update to this standard, expected to be in effect by the time of pipeline installation, the minimum required cover in shipping lanes is 0.2 m plus what is required to sufficiently reduce probability of failure.

Pipelines equal or larger than 400mm OD do not have to be buried according to NEN 3656 Section 9.4.2.6, as in practice they are not affected by fishing gear.

If natural sea bottom variations over the operational lifetime might occur, an appropriate extra cover is to be added to the minimum required cover.

In any case the following conditions must be fulfilled:

- The expected frequency of pipeline damage, due to third parties and resulting in a leak, should be less than 10^{-6} per km of pipeline per year;
- The resulting spillage of liquid hydrocarbons should be less than 100 m^3, 400 m^3, 700 m^3 for a pipeline located within respectively 12 nautical miles of shore, between 12 miles and 25 miles from shore and beyond 25 miles from shore,

3.1. NEN 3656

NEN 3656 provides guidance on the pipeline risk assessment, according the Dutch Authority regulations. The risk investigation and evaluation (RIE) methodology as suggested by NEN 3656 [3] has been applied. Reference is made to Appendix A and B.

4. Design data

All design data considered for the risk and safety calculations for the pipeline are presented in the following subsections and have been extracted from the Basis of Design ref [14]. It should be noted that the pipeline design is still on-going and the pipeline data may change.

4.1. Pipeline Data

The basic pipeline design data considered in the analysis are presented in the tables below. Table 2 presents the data of the pipeline, while Table 3 presents the material properties of the steel used.

Table 2, Pipeline data

Property	Value	
Product transported	Natural gas (dew-pointed gas and condensate)	
Design life	25 years	
Approximate length	14.637 km	
Steel material grade (ISO3183-NEN 3656)	L360 / X52	
Pipe outside diameter	20"/508 mm	
Wall thickness	20.62 mm	
Wall thickness tolerance	-/+ 1.5mm (HFI)	
Corrosion Allowance	5mm	
Minimum subsea hot bend radius	2540 mm (5D)	
Coatings and insulation		
Anti-corrosion coating	3 Layer Poly-Propylene	
Anti-corrosion coating thickness	3 mm	
Anti-corrosion coating density	900 kg/m3	
Heat insulation	NA	
	Un-buried	**Buried**
Outer coating type	Concrete Weight Coating	none
Outer coating thickness	140 mm	-
Outer coating density	3300 kg/m^3	-

Table 3, Material properties

Property	Value
Material (ISO 3183)	L360
Density (kg/m3)	7850
Specified Minimum Yield Strength at 20C (MPa)	360
Specified Minimum Yield Strength at 50C (MPa)	360
Specified Minimum Tensile Strength at (MPa)	460
Youngs Modulus (GPa)	207
Poisson ratio (-)	0.3
Thermal expansion coefficient (m/m C)	1.17 x 10^{-5}

Additional line pipe properties.

NEN 3656, require a number of pipeline material mechanical properties. These un-quantified measures provide additional safety margins (plastically, ductility and cracking) to resist the pipeline against damages and prevent catastrophic ruptures. These measures are among others:

- Ratio Yield/tensile strength ≤ 0.90, to allow plasticity margin for installation purposes;
- Charpy-V-test additional to line pipe code, to prevent ductile propagation and brittle fracture;
- Low carbon equivalents in material composition and weld zones to prevent hardness and reducing cracking susceptibility;

4.2. Key facility coordinates

The following platform and target box locations have been derived from Ref. [17] and are presented in Table 4.

Table 4, Key Facility coordinates

Item	Northing (m)	Easting (m)
N05A Platform	5 954 650	721 607
NGT hot tap location	5 940 532	718 766
N05A Platform target box	5 954 608	721 622
NGT hot tap target box	5 940 549	718 738
Water depth at N05A Platform	Ca. 26 m LAT	
Water depth at NGT hot tap	9.8 m LAT	

4.3. Pipeline Bathymetry and Route

The intended target boxes at the ONE-Dyas platform and the NGT hot tap are shown in Figure 2.

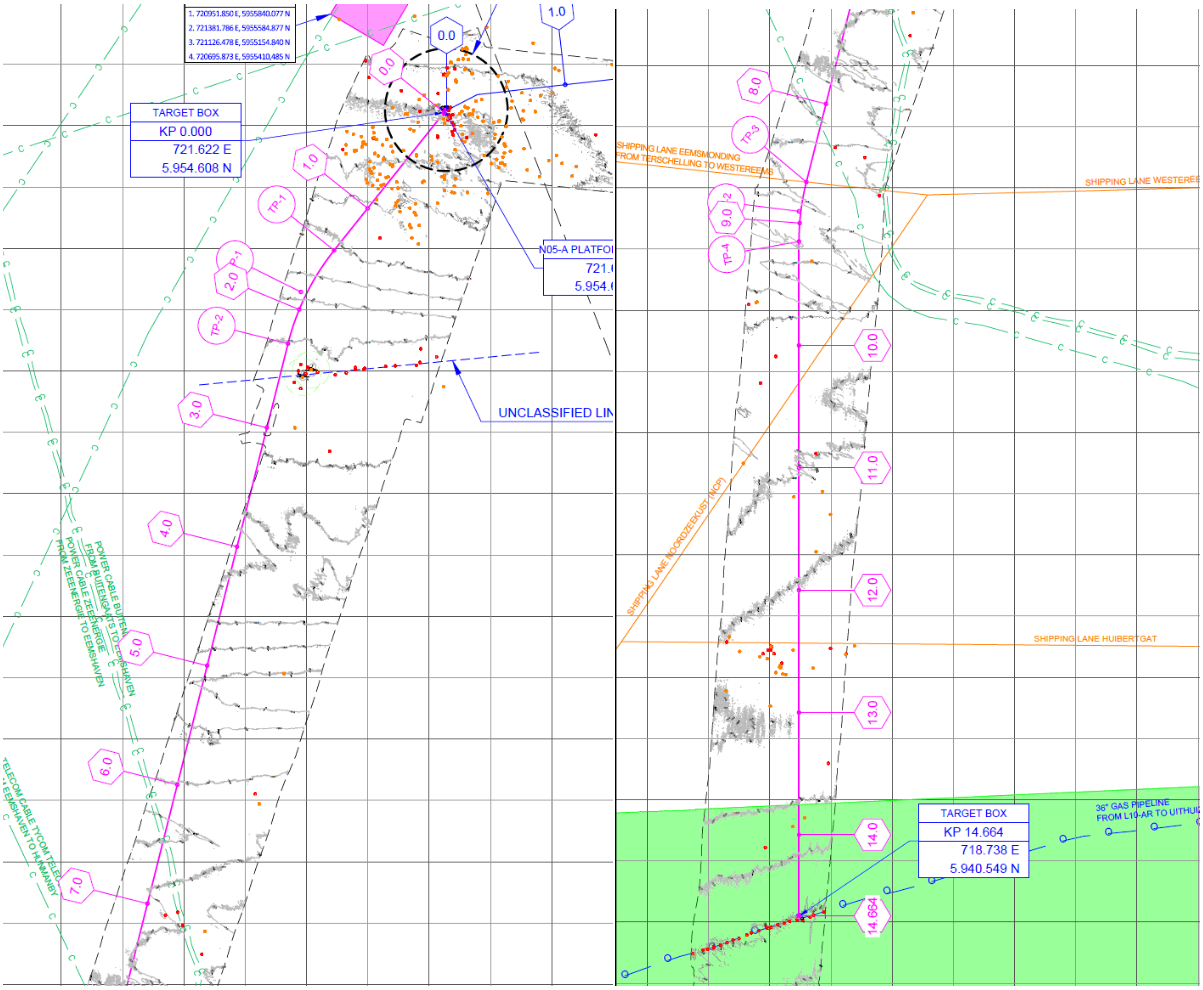


Figure 2, Pipeline route overview

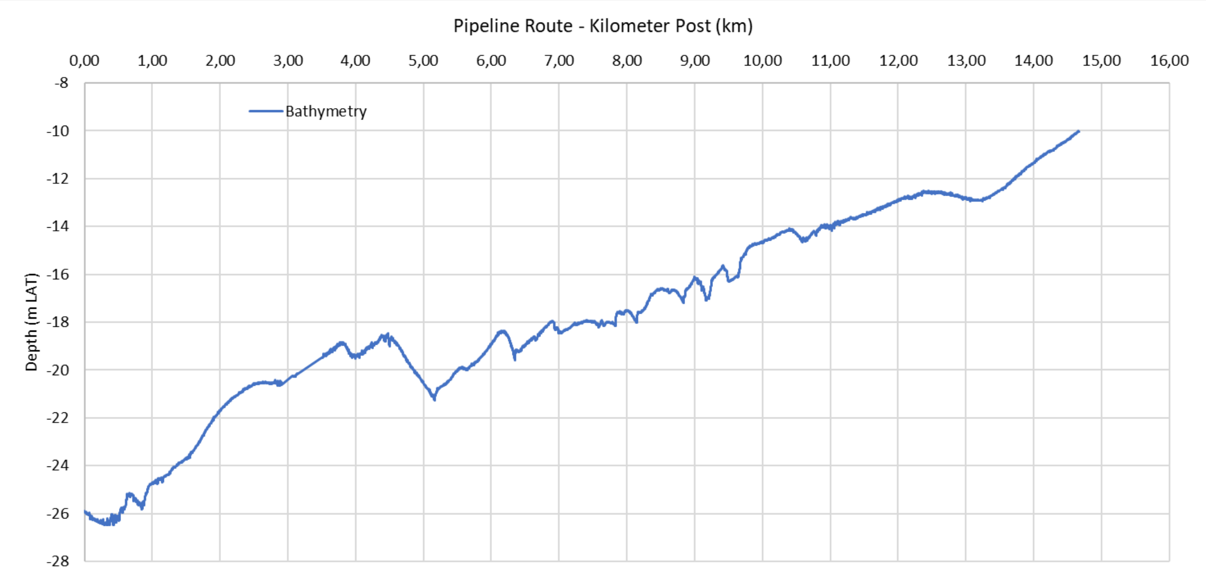


Figure 3, Bathymetric profile along the proposed pipeline route from platform N05A to NGT hot tap, ref [18].

4.4. Seabed Characteristics

The seabed is covered with fine to medium grained SAND generally thickening towards the South ref [16]. Sand was absent (or less than 0.5m thick) from KP 0.430 to KP 0.450, KP 0.757 to KP 1.045 and near KP 5.0 (channel), where the subsoil consists of sand with layers of clay. The soil properties are based on assumptions with reference to the geo-surveys reports, ref [16]. The 0.5 m top layer consists of mobile and loose sand properties. The clay outcrops are regarded as hard soil and to the South the subsoil sands are assumed to be medium.

4.5. Backfill and Rock berm properties

Backfill.

The natural backfilling of the trench is assumed to be loose sands.

Table 5, Properties of backfill material

Property	Value
Soil type	Sand
Submerged weight (kg/m3)	850
Angle of internal friction ϕ, [deg]	28

Rock Dump.

The following properties are considered for the rock dump, as given in Table 6.

Table 6, Rock dump properties

Property	Value
Rock Density [kg/m3]	2650
Porosity [%]	30
Submerged Weight γ, [kN/m^3]	11.4
Angle of internal friction ϕ, [deg]	40

5. Hazards

The N05A pipeline hazards have been qualified in the risk assessment (RIE) workshop. Appendixes A and B presents the workshop attendees, Risk matrix, Risk register and Action list.

5.1. Hazards

Submarine pipelines are subject to various hazards, and are generally divided in the following categories:

- Design, Fabrication and Installation hazards;
- Natural hazards (slope instability, seismic activity, severe storm, erosion);
- Third Party damage (navigation, fishing);
- Corrosion threats;
- Structural threats;
- Operational and Process hazards;

During the workshop, all the threats were considered and assessed whether these are plausible, what potentially causes them and with what potential effects, which initial barriers are regarded in the design, assessing the risk being the combination of likelihood and severity and which controls and safeguards measures will be taken to mitigate the risk to an acceptable level or if an ALARP analysis is required.

It should be noted that this risk assessing is a "dynamic" process that requires updating, when the project is progressing into the following phases.

5.2. Classification of damage

The potential effect of hazards will be pipeline damage and ultimately loss of containment. The main topic of this report is Third Party damage and in order to perform analyses, damages are divided in four classes varying in severity according [11], see Figure 4.

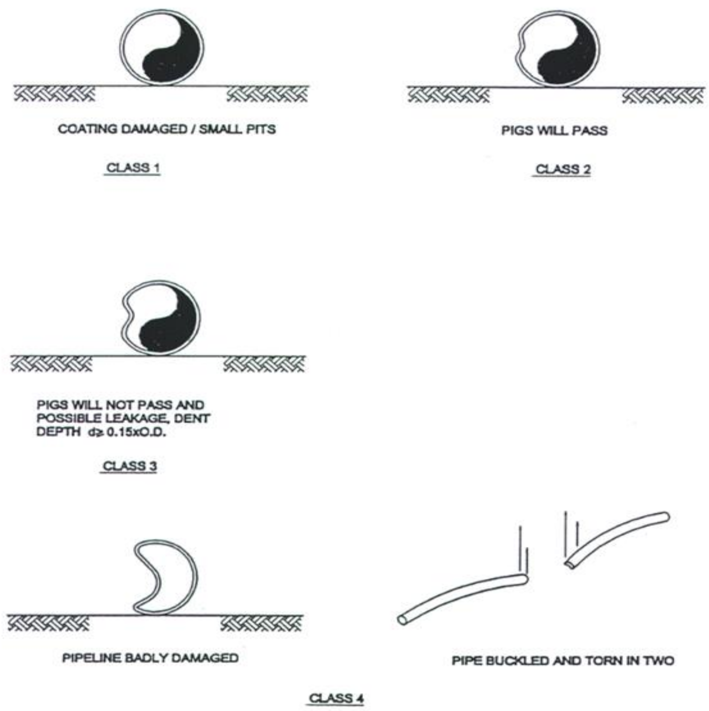


Figure 4, Damage classification

All consequences of third party threats like dropped objects and dropped and dragging anchors are modelled such that they will result in one of the damage classes.

CLASS 1:

Damage to the coating system is denoted as class 1 damage. This type of damage is not serious on the short term, basically limited to damage to the pipeline coating. On the long term, it may have serious consequences such as over-stressing or fatigue due to spanning, forced corrosion due to simultaneous damage of the corrosion coating or loss of anodes and pits in the steel. Such deficiencies, however, will be discovered in time during routine inspections of the pipeline.

CLASS 2:

Small plastic deformations with dents up to 15% of the pipe diameter, 76 mm for the 20-inch pipeline under consideration for this project is denoted as class 2 damage.

Dents up to 10% of the pipe diameter (50.8 mm) are hard to detect and require a caliper pig for detecting. Gauging pigs will pass such dents without being deformed.

Dents up to 15% of the pipe diameter can be nominated as small plastic deformations but are certainly not an immediate jeopardy for the pipeline operation and will not lead to pipeline damage resulting in a leak.

CLASS 3:

Plastic deformations with dents more than 76 mm (15 percent of the pipe diameter for the 20-inch pipeline) is denoted as class 3 damage.

This type of damage becomes serious for the operator, as pigs may not any longer pass the damaged section. Moreover, the possibility of a leak in the pipeline due to damage cannot be excluded. A study from Rijkswaterstaat, Directie Noordzee specifies that for deformations more than 15% of the outside diameter the probability of damage resulting in a leak by dropping anchors is 1.0.[1]

CLASS 4:

Class 4 damage refers to large pipeline deformations and total rupture of the pipeline.

Obviously, Class 4 damage is more serious than Class 3 damage for both operator and controlling agency. The occurrence of a leak in the pipeline is very likely.

Objective of the risk assessment is to determine likelihood of occurrence of Class 3 damage due to third parties and the probability of pipeline damage resulting in a leak.

The safety of the pipeline shall be in accordance with the rules stipulated by the Dutch Authorities as discussed in section 3.

5.3. Dropped object classification Methodology

Methodology and object classification of dropped objects is taken from Table 7, DNV RP-F107 [11]:

Table 7 Overview object classification

No	Description	Weight in air (mT)	Typical objects
1	Flat/Long shaped	< 2	Drill collar/casing/scaffolding
2		2 – 8	Drill collar/casing
3		> 8	Drill riser, crane boom
4	Box/Round shaped	< 2	Container (food, spare parts), basket, crane block
5		2 – 8	Container (spare parts), basket, crane block
6		> 8	Container (equipment), basket
7	Box/round shaped	>> 8	Massive objects, e.g. BOP, pipe reel etc.

With the hydrodynamic properties as specified in Table 8..

Table 8, Overview hydrodynamic coefficients

No	Description	Drag (Cd)	Inertia (Ci)	Added Mass (Ca)
1,2,3	Slender shape	0.7 – 1.5	1.0	0.1 – 1.0
4,5,6,7	Box shaped	1.2 – 1.3	1.0	0.6 – 1.5
All	Misc. shapes	0.6 – 2.0	1.0	1.0 – 2.0

The crane on the N05A platform is located on the North side of the platform, ref Appendix G. All load handling will take place at that side. However the crane can reach the other side, but with reduced lifting capacities of 5 mT. A low probability for dropped objects will remain.

Box shaped objects such as containers typically have a relatively large frontal area for its mass, resulting in a low impact velocity. The most probable objects to damage the spool are therefore pipe-shaped objects. A range of typical tubular and non tubular objects and the relevant properties are listed in Table 9.

Table 9, Dropped object properties

Object	Unit	1	2	3	4	5
Outside diameter, OD	[m]	0.47	0.54	0.6	0.64	2
Mass object in air, M	[kg]	650	1038	1495	5000	12000
Length	[m]	0.74	0.85	0.95	1	1.2
Volume steel, V_{steel}	[m^3]	0.083	0.132	0.190	0.637	1.6
Steel cross area, Ac	[m^2]	0.112	0.156	0.200	0.637	1.274
Wall thickness, WT	[m]	0.076	0.092	0.106	0.317	0.203
Internal diameter, ID	[m]	0.318	0.357	0.387	0.416	1.6
Added mass, M_a	[kg]	84.9	135.5	195.2	783.4	1880

5.4. Dropped and Dragging anchor methodology

All ships crossing the pipeline pose a threat that its anchor will be applied for emergency or for regular anchoring. The weight of the anchors has a more or less defined relation with ships DWT's. The damage is caused by dropping directly on the pipeline, similar to dropped objects. The damage is caused by dragging whereby the anchor is penetrating in the seabed and moved forward by ships kinetic energy and/or its propulsion.

Both damages may result in dents and follow the presented damage classes. Hooking anchors especially for exposed or shallow buried pipelines may get damaged by overstress, buckle and large displacements. The damage criteria is a maximum allowable strain of 5%. A hooked pipeline will display multiple damage features, e.g. dents and strain.

6. Risks analysis of other hazards

In this section the other than third Party interference hazards are briefly discussed.

For the detailed risk assessment reference is made to Appendix B.

During all pipeline phases, a pipeline integrity management system (PIMS) should be in-place. In general this is a risk-based system of inspecting and monitoring, whereby continuous enhancement keep the risk levels within the acceptance levels.

6.1. Design, Fabrication & Installation (DFI)

The pipeline design is based on the pipeline code, NEN 3656. By complying to a code all design aspects will be addressed and guidance is provided how the design analyses shall be made. The final design will result in a reliable pipeline, meeting its intended service life.

DFI threats should not result in pipeline damages if addressed in early stages. Main threats are related to project risks as schedule delay and increased costs.

6.2. Natural hazards

Natural hazards like liquefaction and scour require attention. Natural hazards to a pipeline are slope instability, seismic activity, severe storms, and erosion.

Main natural threats considered in this project are related to the wave-induced impact of the shallow water parts and the sand mobility of the Eems-Dollard Estuary. Impact of these dynamics need to be analyzed.

Typical natural hazard pipeline damages are buckling and ruptures as a result of large displacements. Fatigue can be an issue when pipeline get exposed due to scour.

6.3. Corrosion

The fluid in the pipeline is water dew-pointed wet gas, where liquids were separated, with only condensate added to the gas for export to shore. Corrosion inhibition is considered.

Pipeline corrosion in general comes with different corrosion morphologies and failure modes, from local and general metal loss to cracking.

External corrosion is mainly the exposure when third party damages occur that effects the pipeline coating and potentially lead to external corrosion threats.

6.4. Structural

Riser clamping is a common point of interest. Too much rock berm loads may lead to structural threats. Often structural threats originated from other root causes.

6.5. Operational/process error

Operational hazards will be managed by general company procedures, captured in PIMS.

Hydrate blockage might be a threat to consider.

7. Risk analysis of third party hazards

7.1. General

Potential damage to the pipeline by marine traffic can be caused by the following hazards:

- Riser damage caused by platform collision;
- Damage due to the fishing gear;
- Dropped and dragging anchors;
- Sinking of vessels;
- Damage of dropped objects near a platform;

The probability of these threats are related to the ship traffic density ate the location. The consequence of all of these impacts result in pipeline dents. Whereby a dent of ≥ 15% of the pipeline diameter has a consequence damage of class 3 and will lead to loss of containment.

The analyses are performed in this section. The analyses consider the pipeline protection by examining the resistance of a single barrier or combinations of bare steel of the pipe wall, CWC, sand cover and/or rock berm as protection measure.

7.2. Shipping traffic

Figure 5 indicates the density of sea traffic. The map originates from Marin report, ref [15] used for the platform collision study. The AIS data is collected over full 2017 of all ships equipped with (active) AIS transponder. Ships above 300 DWT and fishing vessels > 15 m, have a mandatory requirement for applying the AIS transponder.

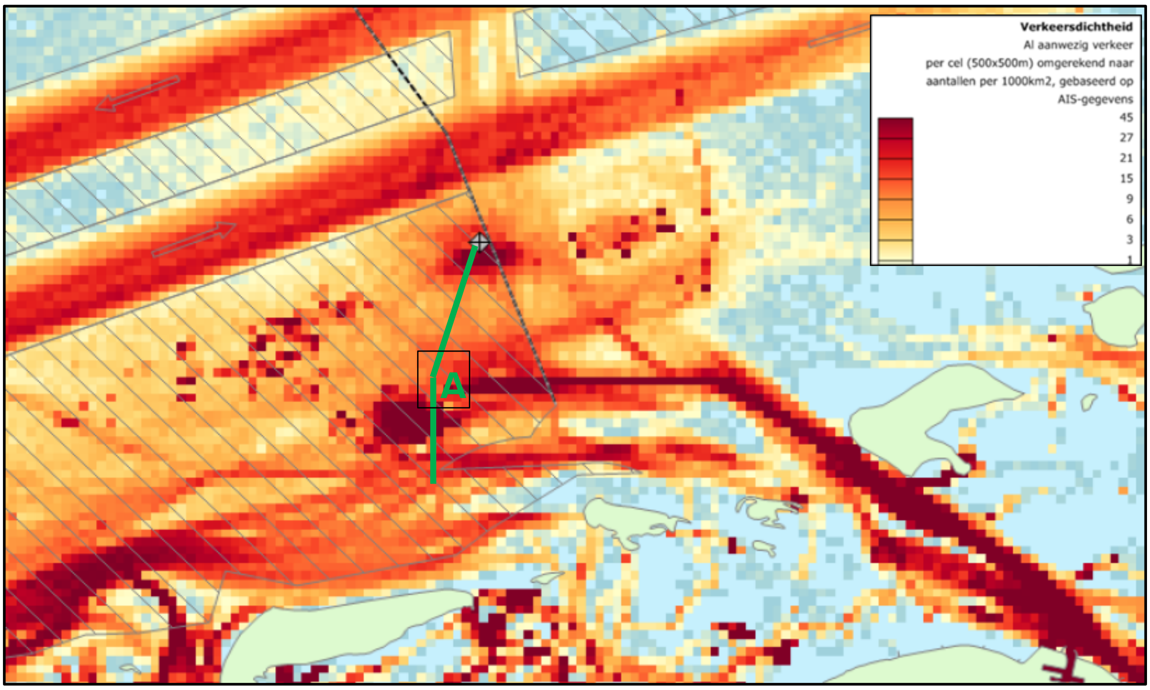


Figure 5, Vessel density maps, based on AIS over 2017 ref [15]], with platform and pipeline. All vessel sizes are shown.

For analyses performed in this report the density map of Figure 5 is applied, as the methodology is based on ships density and on a ship DWT composition typical for the Dutch sector of the North Sea. It should be noted that many of the smaller vessels do not pass this area. They will remain near shore or take the routes South of the Wadden islands.

The maximum ship density applied in this study is 45 per 1000 km^2. It is assumed that the average ship speed is 4.5 knots. Ships entering the anchor or fairway will have a reduced speed. Leaving vessels will be faster.

The N05A pipeline, from the platform in the North to the NGT hot tap in the South, is situated in the Eems-Dollard estuary, which has a fairway to Dutch and German ports. The fairway is a 200 m wide, dredged and maintained at approx. 14.5 m below LAT, channel. The fairway is a highly regulated corridor, where entering or leaving vessels are regulated by a traffic control centre. There is a requirement for pilotage and tug boat assistance from DWT ≥ 10.000. Whereby the rendez-vous point is at the point A (Figure 5) at the North Sea side of the fairway. This regulation results in ships waiting in the pilot waiting zone to get permission to enter the fairway.

The current projected pipeline route is outside the fairway, but it can be seen from the Figure 5 that ships wait at the entrance of the fairway.

7.3. Ships classification data

Ships are divided by ship classification systems.

Table 10, ship composition

Vessel size	Anchor weight	Percentage
DWT ≤ 3.000	625 kg	74.0
3.000 < DWT ≤ 10.000	2000 kg	6.3
10.000 < DWT ≤ 100.000	13500 kg	18.2
DWT > 100.000	17000 kg	1.5
Total		100.0

In Table 10 the classes of ships and ship composition, considered to be representative for the North Sea and for this area, are given.

7.4. Ship accidents

Table 11 presents the numbers of incidents , relevant for the Dutch sector North Sea , Ref[6].

Table 11, incidents and emergency numbers

Incident	Number of incidents	
	2004-2012	per year
Total 2004 – 2012: Sea and delta	346	38,4
Number fishing + shipping + Ferries total Netherlands	534	59,3
Total number of shipping incidents	834	93
Number fishing + shipping + Ferries total sea and Delta	221,5	24,6
Sinking	1,0	0,1

7.5. Riser damage caused by platform collision

A platform collision study has been performed, by Marin [15]. This collision report has determined the collision frequency caused by passing ships. The high risk of collision is dominated by the large vessels passing at high speeds in the Southern main shipping lanes, North of the platform. The collision is determined on drifting and ramming ships hitting the platform, resulting in a total risk of 3.66 10^{-3}/year or once every 273 years.

The study has excluded the consequence of a collision, however stated that an energy impact of ≥200 MJ has a catastrophic impact on the platform. This occurs 1.04 10^{-3} or once every 961 years.

Risers follow the pipeline code, NEN 3656 and shall comply with the failure frequency of 10^{-6}/year.

Even if the risers are located inside the jacket and shielded from direct collision impact, it is likely that Class 3 damage will occur when 200 MJ energy impacts the platform.

The platform is subject to risk mitigation or ALARP assessments where the outcome is not yet available to implement in this report. It is assumed that the riser along with other pressure contained equipment is captured in these assessments.

7.6. Risk analysis fishing gear impact

Fishing gear impact is considered a third party threat to the un-buried pipeline and to the pipeline coating. It also presents a threat to the fishing gear, the vessel and its crew.

According to NEN3656 Section 9.4.2.6, pipelines larger than 400 mm in diameter are in practice not affected by fishing gear, which is applicable to the current pipeline with an outer diameter of the steel pipe of 508 mm plus possible additional CWC.

A further mitigating measure is that the pipeline will be unburied for a short period of time during installation and during this time the position will be clearly identified to marine traffic, including fishing boats. Guard vessel(s) will also be used to safeguard the pipeline from external impacts.

7.7. Sinking ships

The average number of sinking ships is 1 per 9 years according [6] and the total distance sailed by ships is 21.6 x 10^6 nautical miles, the frequency of ships sinking is 24.6/year. Consequently, the probability that a ship will sink is equal to $P_{accidental}$ = 5.14 x 10^{-9} per sailed nautical mile per year.

Approximately 85% of all sunken ships had a DWT of less than 500. Taking 500 DWT as an average, the characteristic length of the ships is 50m. The critical corridor in which a vessel can sink and hit the pipeline is 100m wide, with the pipeline in the center.

The course of a ship in an emergency has a random orientation, not all the ships which sink in the critical corridor, will hit the pipeline. Only a fraction of $1/\pi$ of the ships sinking in the critical area will hit the pipeline.

As stated section 7.2, a shipping density of 45 ships per 1000 km² is assumed within the area of the North Sea where the pipeline will be placed.

The average sailing speed is 4.5 nautical miles per hour, this means that an average vessel will sail 24 x 365 x 4.5 = 39420 nautical miles per year. The sailed distance (L_s) within the area of 1000 km² is therefore equal to the number of nautical miles per year multiplied by the shipping density:

$$L_s = 39420 \cdot 45 = 1.77 \cdot 10^6 \; nm$$

The distance sailed in the critical pipeline corridor of 100m per km pipeline length equals to

$$L_c = L_s \frac{0.1}{1000} = 177.4 \; nm$$

The probability of sinking ships on the pipeline (P_s) is equal to the frequency of sinking ships, $P_{accidental}$, multiplied by the sailed nautical miles in the critical pipeline corridor L_c.

Consequently, $P_s = P_{accidental} \cdot L_c = 5.14 \cdot 10^{-9} \cdot 177.4 = 9.13 \cdot 10^{-7}$ accidents per km per year in the critical pipeline corridor due to sinking ships. Taking the random directionality into account, the probability of a sinking ship on top of the pipeline is $\frac{P_s}{\pi} = 2.90 \cdot 10^{-7}$ per km per year and well below the NEN 3656 acceptance criterium of 1.0 x 10^{-6} /year.

When a ship sinks, it will eventually come to rest on the seabed. If this occurs just above the pipeline, it would depend on the local strength of the shell of the ship whether the pipeline would be dented or damaged with leakage.

Due to the relatively low vertical velocity of the sinking ship when hitting the pipeline, one can consider the loading on the pipeline as quasi static. The kinetic energy carried by a sinking ship of 3000 DWT (74% of the vessels) is in the order of 6kJ per m^2. The energy resistance capacity of the un-buried pipeline with CWC is indicative 120kJ, refer to section 7.10. A sunken ship will likely provide a more even load distribution.

To penetrate 0.2m cover approximately 30kJ of kinetic energy per m^2 contact area is required. It is unlikely that the buried pipeline with a depth of cover of 0.6 m will be affected by a sinking ship.

The un-buried pipeline with 140 mm CWC has a significant impact resistance. However impact cannot be excluded.

7.8. Frequency of dropped and dragging anchors

Dropping anchors near the pipeline pose a risk, as it can potentially hit and damage the pipeline.

Anchoring of work boats outside platform areas is not expected to be hazardous to the pipeline as the crews of such vessels are always fully aware of obstacles in their work sector and anchoring is consequently carefully planned. Furthermore, anchoring of a workboat is often done with assistance of a special anchor vessel.

Reasons for anchoring can be divided in two groups, including:

- Regular anchoring, to await the boarding of a pilot or permission for entering the harbor, waiting for further sailing orders of the owner or for cleaning and maintenance.
- Emergency anchoring, following an accident such as fire, engine failure or collision.

In case of regular anchoring, a ship’s captain will inspect his sea charts, avoid obstacles and preferably choose an area assigned for anchoring. For that reason, regular anchoring is not considered to be a risk factor for the safe operation of a pipeline.

In the event of an emergency, it may be expected that most of the ship’s captains will inspect their sea charts before dropping an anchor. In addition, many captains prefer not to anchor at all in emergency situations. However, it cannot entirely be ruled out that some of them decide to drop an anchor impulsively. Following this reasoning, it is assumed in this study that in 25 percent of emergency situations, anchors are dropped without prior inspection of the sea charts. In such case, the anchors are considered to be dropped at random; some of them will land in the vicinity of the pipeline and may create a critical situation for the pipeline.

The probability of anchor drops or dragging of the anchor near the pipeline is a function of the following factors:

- The chance that a ship faces an emergency.
- The width of the corridor, wherein anchor drop or drag becomes a risk factor for the pipeline.
- The length of the hazardous zone, this being a function of the angle between the vessels’ course and pipeline.
- Traffic density and composition in the identified region.
- Critical ship DWT causing Class 3 damage in the case of drop/drag.
- Type and mass of anchor used

The traffic density/composition and the chance that a ship faces an emergency is a function of the registered accidents and emergency situations ref.[6] and listed in in section7.3 and 7.4.

The probability that a vessel will be involved in an accident or will face an emergency depends on the distance sailed by a vessel. Using the data presented in ref. [6], the cumulative distance sailed per day by all vessels is determined being 21.6 million nautical miles.

Considering the total number of ships involved minus the ships running aground 24.5/year (24.6/year–sinking 0.1 /year). The frequency of an accident or emergency is:

$P_{accidental} = \frac{24.6-0.1}{21.6 \cdot 10^6} = 1.13 \cdot 10^{-6}$ accidents per sailed nautical mile per year.

The maximum dragging distance of an anchor depends on the type, mass, and the soil conditions. For smaller anchors in sand the dragging distance is less than 10m, for heavier anchors it is 10–15m. In this study, the critical corridor is taken as 30m (15m each side of the pipeline) for all anchors.

When the anchor is dropped in the inner part of the critical zone it will hit the pipeline directly. The width of this anchor drop sector is a function of the anchor width. The width of a large anchor is taken as 2.5m (see also Appendix C for anchor sizes) resulting in a sector width for anchor drop of 5.0m.

The probability that an anchor, when dropped in the critical zone, will directly fall on top of the pipe is therefore 5/30. Consequently, the probability that dropping an anchor in the critical zone will result in anchor drag towards the pipeline is 25/30.

The frequency of accidents per year occurring in the critical zone is calculated as follows:

It is assumed that in 25 percent of the events that an accident occurs, an anchor will be dropped without first consulting any charts, as discussed above. Furthermore, it was shown that the probability that a dropped anchor within in the critical zone directly hits the pipeline is 5/30. The frequency directly hitting the pipeline per km per year can thus be calculated.

The direction of the dragging anchor is variable and the portion of dropped anchors that are dragged towards the pipeline is accounted by multiplying the total number by a factor 1/π.

The distance sailed per year in the critical pipeline corridor of 30m per km pipeline length is equal to:

$L_c = L_s \frac{0.03}{1000} = 53.2\, nm$

The probability of an accident due to emergency anchoring P_{anchor} per km per year in the corridor is equal to the probability of accidents per sailed nautical mile P_{acc} multiplied by the sailed nautical miles per year in the corridor L_c and apply the factors 0.25 and 5/30 to account for the probability of anchor drop and anchors directly falling on the pipe P_{drop}:

$P_{anchor} = P_{accidental} \cdot L_c = 6.04 \cdot 10^{-5}$ emergency anchoring per kilometer per year

$P_{drop} = P_{anchor} \cdot \frac{5}{30} \cdot 0.25 = 2.52 \cdot 10^{-6}$ anchors falling on the pipeline per kilometer per year.

The probability of an accident due to dragging anchors P_{drag} outside the shipping lane is equal to the probability of emergency anchoring multiplied by 25/30 accounting for the anchor drag length of 25m relative to the length of the critical area 30m. Further factors of 1/π and 0.25 are applied to account for the directionality and the probability of anchoring.

$P_{drag} = P_{anchor} \cdot \frac{25}{30} \cdot \frac{1}{\pi} \cdot 0.25 = 4.00 \cdot 10^{-6}$ accidents per km of pipe per year due to dragging anchors

7.9. Damage due to dropping and dragging anchors

Not all anchors dropped or dragged in the critical zone will result in leakage. There are two major factors contributing to this. First is the absorption of energy by the soil covering the pipeline, second is the allowable deformation of the pipeline before leakage occurs.

An anchor dropped from a ship first penetrates vertically into the seabed. The depth of penetration depends on the weight and shape of the anchor and characteristics of the seabed soils.

As the ship continues to move after the anchor has reached the seabed, the anchor chain tightens and pulls the anchor over until it reaches a horizontal position on the seabed. From this position the flukes gradually work down into the soil until the body of the anchor is either partly or wholly embedded in the seabed and the anchor attains its maximum holding power.

To represent the entire range of anchors, anchors with masses of respectively 1000kg, 5000kg, 10000kg, and 15000kg have been considered in this study. Typical anchor parameters are given in Appendices C. Based on published test results an average drag distance of 10m has been selected as appropriate for the sizes of anchors considered. [9]

The passive soil resistance determines the maximum holding power of an anchor. When this holding power is exceeded, some anchors drag horizontally through the soil, while others rotate and will break out and dig in again. When an anchor attains its maximum holding power at the end of dragging, it also has embedded a certain depth below the sea bottom.

A pipeline, which is resting in or on the seabed, is hit by an anchor either vertically when the anchor is dropped on top of it, or horizontally when the anchor is dragged towards the side of the pipeline.

Both types of loading deform the pipeline differently and are discussed below.

7.10. Damage due to anchor drop

The kinetic energy of the falling anchor is absorbed by the soil and by deformation of the pipeline. To visualize the plastic deformation energy, the model in Appendix D is used.

The energy required for plastic deformation is a function of the pipeline characteristics and extent of deformation in accordance with equation:

$$E_p = 2\,\sigma_t\, t_{EOL}^2\, \delta\, \sqrt{2},$$

in which:

$$t_{EOL} = (1 - wtt) \cdot wt - t_{cor},$$

where

- t_{EOL} is the wall thickness of the pipeline at the end of life;
- wtt is the wall thickness tolerance, as defined in Table 2 (50% taken into account);
- t_{cor} is the internal corrosion allowance, as defined in Table 2 (50% taken into account);
- δ is 15% of the pipeline OD, so 41 [mm];

For the given material properties and wall thickness, provided in section 4.1. This leads to a plastic energy of 20.16 [kJ]. It should be noted that the CWC of 40 and 140 mm provides an additional energy absorption resistance of 34 and 120 [kJ], respectively (indicative). This is based on linear extrapolation of concrete coating absorption energy, as indicated in section 4.6 of ref[11].

The maximum allowable deformation (δ) is 15 % of the pipeline diameter, further deformation is associated with leakage. To establish the impact velocity of the anchor it is necessary to determine the impact velocity of the anchor when it reaches the seabed. During its descend to the sea floor, the anchor is subjected to the forces of gravity and drag. Drag can be computed from:

$$F_d = \frac{1}{2}\rho V^2 C_d A$$

If the anchor is released from sufficient height, drag and gravity will be in balance at a certain speed of descend, known as terminal velocity. Terminal velocity can be calculated from:

$$v_T = \sqrt{\frac{2 \cdot g \cdot (m - V \cdot \rho_{water})}{\rho_{water} \cdot C_d \cdot A}},$$

in which:

- m is the mass of the dropped object;
- g is the gravitational constant;
- V is the volume of the object (the volume of the displaced water);
- ρ_{water} is the sea water density, 1025 [kg/m^3];
- Cd is the drag coefficient, which is a function of the dropped object shape;
- A is the projected area of the object in the flow direction;
- v_T is the terminal velocity;

The kinetic energy of the anchor is computed from

$$E_k = 0.5(M + M_a) \cdot v_T^2$$

With the added mass given by

$$m_a = \rho_{water} \cdot V \cdot C_a,$$

in which:

- C_a is the added mass coefficient, which is a function of the object shape;

The calculation of the kinetic energy as a function of the anchor mass is provided in Appendix E.

The absorption of energy (E_{pen}) by the seabed can be derived with the Brinch-Hansen method for the soil bearing capacity

$$E_{pen} = \int_0^{d_p} F(y)dy$$

Where:

y is the penetration depth [m]

d_p is the depth of the soil cover above the top of the pipeline [m]

$F(y)$ is the soil bearing capacity at a certain depth [N], given by:

$$F(y) = A \cdot \left(c\ N_c\ S_C\ D_c + q_0\ N_q\ S_q\ D_q + 0.5\ \gamma\ B\ N_\gamma\ S_\gamma\ D_\gamma\right)$$

Where:

A is the frontal area of the anchor [m^2]

c is the cohesion of the soil [N/m^2], for the project under consideration $c = 0$ (ref. [14]);

q_0 is the overburden load at depth y [N/m^2], $q_0 = \gamma\ g\ y$

γ is the submerged density of the soil [kg/m^3], as given in Table 5;

ϕ is the angle of soil internal friction [deg], as given in Table 5;

B is the width of the anchor frontal area [m];

L is the length of the anchor frontal area [m];

N, S and D are dimensionless factors related to the soil bearing capacity, shape of the frontal area, and the depth respectively

$$N_c = \frac{N_q - 1}{\tan \phi}$$

$$S_c = 1 + 0.2 \frac{B}{L}$$

$$D_c = 1 + 0.4 \, \mathrm{atan} \frac{y}{B}$$

$$N_q = e^{\pi \tan \phi} \tan^2 \left(45 + \frac{\phi}{2}\right) \mathrm{F}$$

$$S_q = 1 + \sin \phi \frac{B}{L}$$

$$D_q = 1 + 2 \tan \phi \ (1 - \sin \phi)^2 \, \mathrm{atan} \frac{y}{B}$$

$$N_\gamma = 2 \left(N_q - 1\right) \tan \phi$$

$$S_\gamma = 1 - 0.4 \frac{B}{L}$$

$$D_\gamma = 1$$

Damage will be beyond the 15 % acceptable deformation when:

$$E_k - E_{pen} > E_p$$

Appendix C shows a relation between anchor mass and the frontal area of the anchor.

The calculated absorption energy as a function of the cover height is provided in Appendix E.

Using a representative set of anchor masses, a relation between anchor mass and the required minimum soil cover was established, as presented in Figure 6.

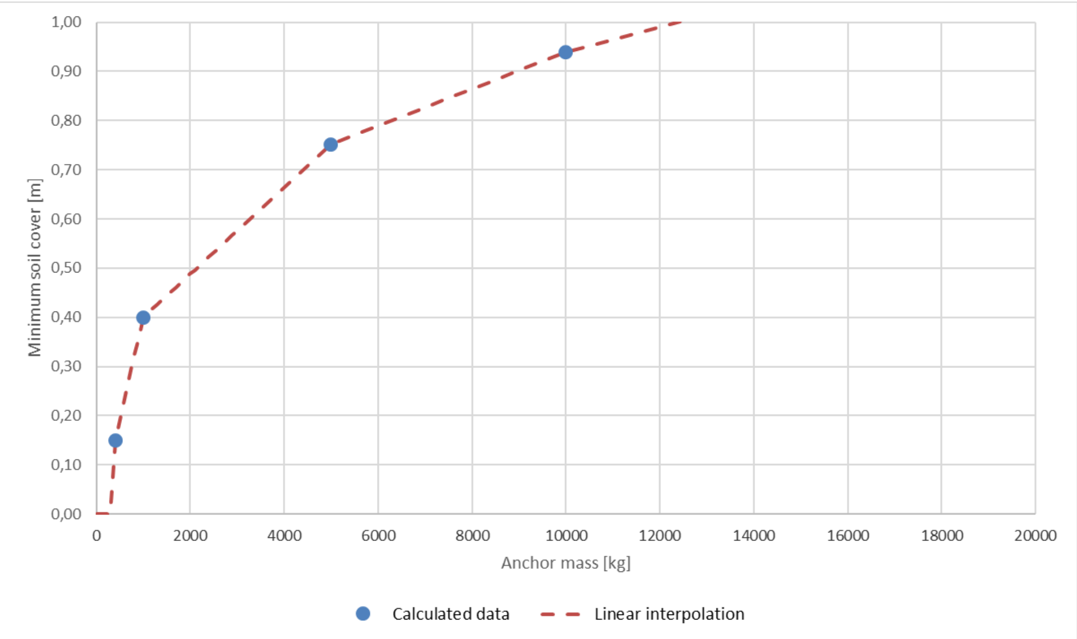


Figure 6 Required minimum soil cover as function of anchor mass (valid > 1200kg)

Impact from dropped anchors start at 1100 kg for pipeline without CWC and 4150 kg for pipelines with 140 mm CWC (this last figure is only indicative).

7.11. Damage due to anchor drag

If the pipeline is hit by a dragging anchor, it first experiences an impact load, followed by a sustained load when the anchor hooks behind the pipeline and the anchor chain/cable is straightened.

The impact loading and its consequence for the pipeline can be found from the results above. It is logical to expect that the velocity of the dragged anchor is very low and of the same order as the surface current velocity, which keeps the ship without engine power moving. With an anchor drag velocity of 1m/s the effect of the impact load is negligible due to the anchor velocity at the time of a direct drop.

For that reason, the pipeline damage assessment following an anchor drag is only done for the second phase of loading, when the anchor hooks and starts to drag the pipeline. The ultimate load to which the pipeline is exposed is assumed to be equal to the design load of the anchor chain.

If a pipeline has sufficient cover it is possible that the dragging anchor will not reach it. This cover depth is equal to the depth of anchor embedment after being dragged minus half of the pipe diameter, as an anchor which hits the pipe on its top half will be dragged over the pipeline without causing any serious damage.

The depth of penetration or embedment as a function of the anchor size is illustrated in Appendix C. This relationship is valid for sandy soils like those found along the considered pipeline route. To investigate the uniformly supported pipeline exposed to a concentrated load, a mechanical model is selected based on the following assumptions:

- The pipeline is supported by soil which will yield, and therefore, the soil resistance equals the ultimate soil resistance.
- Three plastic hinges represent the deflection pattern of the pipeline.
- The maximum load capacity of the pipeline is reached when the stress level in the fully plastic cross section reaches the breaking strength of steel.

Based on the above assumptions, the maximum load capacity can be determined by considering an energy balance.

The ultimate load bearing capacity due to energy absorbed by the plastic hinges and soil is equal to:

$$F = 4\sqrt{M_p R}$$

Where:

M_p is the plastic moment [Nm], $M_p = D^2\, t\, \sigma_t$

D is the outside pipe diameter [m]

t is the pipe wall thickness at end of life [m]

σ_t is tensile strength of steel [N/m^2]

R is the resistance of the soil behind the pipe [N/m],

$$R = \gamma\, g\, z\, N_q\, D$$

z is the depth of the centerline of the pipe

γ is the submerged density of the soil [kg/m^3], as given in Table 4

$$N_q = e^{\pi \tan\phi} \tan^2\left(45 + \frac{\phi}{2}\right)$$

The maximum anchor drag force to which the pipeline will be exposed is taken to be half of the breaking strength of the chain. According to Lloyd's register of Shipping, the mass of an anchor is related to the link breaking strength of the anchor chain. Appendix C shows a plot of this relationship.

The tension force in the chain is equal to the anchor drag force plus drag of the chain itself on the sea floor and the gravity component up to the ship anchor chain attachment point. To account for these forces the following approximate linear relation is used:

$$T = K \cdot F$$

The factor K depends on whether the pipeline is buried or not, and on the type of anchor considered. For anchors used on merchant vessels, K = 1.1 for an unburied pipeline and K = 1.3 for a buried pipeline. For this project a buried pipeline is considered.

7.12. Probability of damage due to anchor drop and drag

Accounting for the associated vessel Dead Weight Tonnage (DWT), the probability of a dropped anchor resulting in unacceptable damage has been determined. The distribution of marine traffic split into the four groups as discussed earlier in this chapter has been utilized to establish this probability (in percentage) according to:

$P(d) = 100 - \frac{DWT}{3000} P_{0,group1}$; valid for DWT<3,000 mT

$P(d) = 100 - \frac{DWT-3000}{7000} P_{0,group2} - P_{0,group1}$; valid for 3,000 mT < DWT < 10,000 mT

$P(d) = 100 - \frac{DWT-10000}{100000} P_{0,group3} - P_{0,group1} - P_{0,group2}$; valid for 10,000 mT < DWT < 100,000 mT

$P(d) = P_{0,group4}$; valid for DWT >100,000 mT

Dropped anchors

The DWT of the ships which anchors can cause Class 3 damage when directly dropped on top of the pipeline were calculated in section 7.9,. For the associated DWT ranges, the percentage of a group which causes damage by a dropped anchor can be determined, as given in Table 12 (calculation as per Appendix E)

Table 12, Probability of a leak as a function of the critical anchor mass and ToP cover

ToP cover [m]	Critical anchor mass [kg]	Critical DWT [mT]	Traffic > Crit. DWT [%]	Probability of leak X10^{-6}
No CWC				15/27/45 vessels /1000km^2
0.0	1000	4870	41.9	0.39 / 0.70 / 1.17
0.2	1300	6388	35.3	0.33 / 0.59 / 0.99
0.4	2000	10032	19.7	0.18 / 0.33 / 0.55
0.6	3500	18321	18.0	0.17 / 0.30 / 0.50
0.8	7500	44278	12.8	0.12 / 0.21 / 0.36
1.0	13000	95040	2.5	0.01 / 0.03 / 0.04
40 mm CWC				
0.0	2000	10032	19.7	0.18 / 0.33 / 0.55
0.2	3000	15483	18.6	0.17 / 0.31 / 0.52
0.4	4000	21237	17.4	0.16 / 0.29 / 0.49
0.6	5000	27322	16.2	0.15 / 0.27 / 0.45
0.8	8500	51920	11.2	0.10 / 0.19 / 0.31
1.0	14500	113631	1.5	0.04 / 0.04 / 0.04
140 mm CWC				
0.0	4000	21237	17.4	0.16 / 0.29 / 0.49
0.2	4500	24236	16.8	0.16 / 0.28 / 0.47
0.4	6000	33778	14.9	0.14 / 0.25 / 0.42
0.6	8000	48029	12.0	0.11 / 0.20 / 0.34
0.8	12000	83977	4.7	0.04 / 0.08 / 0.13
1.0	16500	142817	1.5	0.04 / 0.04 / 0.04

Dragging anchors

The DWT of the ships which anchors can cause Class 3 damage when directly dragged towards the pipeline were calculated in section 7.9. The relevant properties calculated for anchor drag, can be found in Appendix F. The contribution of the CWC on the resistance against anchor drag is not known, as such the calculation is conservatively performed for the steel pipeline only.

Table 13, Probability of a leak as a function of the critical anchor mass and cover depth

ToP cover [m]	Critical anchor mass [kg]	Critical DWT [mT]	Traffic > Crit. DWT [%]	Probability of leak X10^{-6} 15/27/45 vessels /1000km^2
0.0	1097	5358	39.8	0.35 / 0.64 / 1.06
0.2	1520	7520	30.4	0.27 / 0.49 / 0.81
0.4	1887	9435	22.1	0.20 / 0.35 / 0.59
0.6	2226	11235	19.5	0.17 / 0.31 / 0.52
0.8	2543	12955	19.1	0.17 / 0.31 / 0.51
1.0	2832	14547	18.8	0.17 / 0.30 / 0.50

7.13. Cumulated dropped and dragged anchor damage

The cumulated probability is shown in Table 14.

Table 14, Cumulative probability of anchor drop and drag for buried pipeline

ToP cover [m]	Probability of leak: anchor drop x10^{-6}	Probability of leak: anchor drag x10^{-6}	Total Probability of leak: (anchor drop + anchor drag) x10^{-6}
No CWC	15/27/45 vessels /1000km^2	15/27/45 vessels /1000km^2	15/27/45 vessels /1000km^2
0.0	0.39 / 0.70 / 1.17	0.35 / 0.64 / 1.06	0.74 / 1.34 / 2.23
0.2	0.33 / 0.59 / 0.99	0.27 / 0.49 / 0.81	0.60 / 1.08 / 1.80
0.4	0.18 / 0.33 / 0.55	0.20 / 0.35 / 0.59	0.38 / 0.68 / 1.14
0.6	0.17 / 0.30 / 0.50	0.17 / 0.31 / 0.52	0.34 / 0.61 / 1.02
0.8	0.12 / 0.21 / 0.36	0.17 / 0.31 / 0.51	0.29 / 0.52 / 0.87
1.0	0.01 / 0.03 / 0.04	0.17 / 0.30 / 0.50	0.18 / 0.33 / 0.54
40 mm CWC			
0.0	0.18 / 0.33 / 0.55	0.35 / 0.64 / 1.06	0.54 / 0.97 / 1.61
0.2	0.17 / 0.31 / 0.52	0.27 / 0.49 / 0.81	0.44 / 0.80 / 1.33
0.4	0.16 / 0.29 / 0.49	0.20 / 0.35 / 0.59	0.36 / 0.65 / 1.08
0.6	0.15 / 0.27 / 0.45	0.17 / 0.31 / 0.52	0.32 / 0.58 / 0.97
0.8	0.10 / 0.19 / 0.31	0.17 / 0.31 / 0.51	0.27 / 0.49 / 0.82
1.0	0.04 / 0.04 / 0.04	0.17 / 0.30 / 0.50	0.21 / 0.34 / 0.54
140 mm CWC			
0.0	0.16 / 0.29 / 0.49	0.35 / 0.64 / 1.06	0.52 / 0.93 / 1.55
0.2	0.16 / 0.28 / 0.47	0.27 / 0.49 / 0.81	0.43 / 0.77 / 1.28
0.4	0.14 / 0.25 / 0.42	0.20 / 0.35 / 0.59	0.34 / 0.60 / 1.01
0.6	0.11 / 0.20 / 0.34	0.17 / 0.31 / 0.52	0.28 / 0.51 / 0.85
0.8	0.04 / 0.08 / 0.13	0.17 / 0.31 / 0.51	0.21 / 0.39 / 0.64
1.0	0.04 / 0.04 / 0.04	0.17 / 0.30 / 0.50	0.21 / 0.34 / 0.54

7.14. Shipping Densities

Along the selected pipeline route different shipping densities occur. The pipeline route has been divided into 4 sections for which the highest shipping density will be governing, see figure 7 below and table 15.

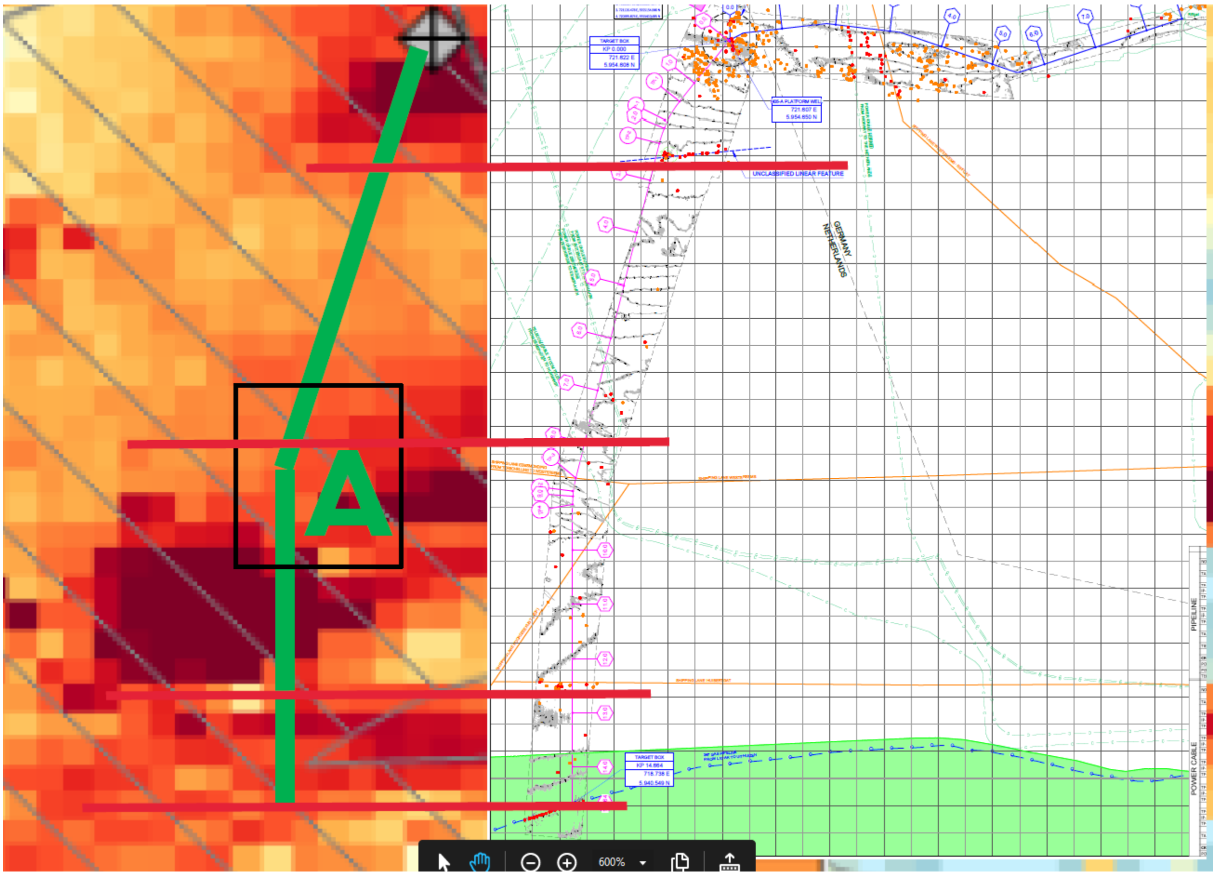


Figure 7 Shipping densities along the pipeline route

Table 15 Shipping densities along the pipeline route

From KP	To KP	Shipping density
0.0	2.7	45
2.7	8.0	15
8.0	12.7	45
12.7	14.7	27

The effect on the shipping density on the minimum burial depth is summarized in table 16.

It should be noted that the CWC thickness of 140 mm has already reached its maximum thickness from manufacturing, handling and installation perspective.

Table 16 Minimum required cover depth

Ship density /1000 km²	No CWC		40 mm CWC		140 mm CWC	
	Depth ToP [m]	Probability 10^{-6}	Depth ToP [m]	Probability 10^{-6}	Depth ToP [m]	Probability 10^{-6}
45	0.7	0.97	0.6	0.97	0.5**	0.90
27	0.3	0.89	0.0	0.97	0.0	0.93
15	0.0	0.74	0.0	0.54	0.0	0.52

Note **: The determined cover depth for 140 mm CWC in the shipping lane considers an update to NEN 3656, expected to be in effect by the time of pipeline installation, where the cover depth in a shipping lane is based on a risk assessment instead of the minimum requirement of 0.6m cover in the 2015 edition.

8. Dropped object analysis

This section describes the used methodology for determining the impact energy due to the dropped objects and the amount of energy absorbed by the rock dump as a function of its height. This approach excludes probabilistic data and is merely a comparison between impact energy of the dropped object and absorbed energy by the cover layer. It is assumed that the spool has the same properties as the pipeline, as a result the same acceptable amount of plastic deformation energy has been used.

The required height of the rock dump near the platforms and tie-in, to withstand the impact energy generated by dropped objects because of crane handling from and on(to) the platform/supply vessel (containers, equipment, pipes etc.), is determined following DNV-RP-F107 [11].

8.1. Dropped object impact energy

Calculation of the kinetic energy (E_k) of a dropped object is performed using the same method as described in section 7.8. As discussed in chapter 5.3, the most likely objects to damage the pipeline are tubular objects such as pipe elements.

Using the data on typical dropped objects as presented in Table 9, the terminal velocity and kinetic energy upon impact are calculated and the results are presented in Table 17. The maximum drop height (Hd) in air is estimated not to exceed 50 [m].

The impact velocity at sea level can be determined using section 4 of ref. [12]:

$$v_{i,a} = \sqrt{2 \times g \times Hd}$$

The characteristic water depth is determine using 4 of ref. [12]:

$$sc = \frac{M + Ma}{\rho_w \, * \, C_d \, * \, A_p}$$

Knowing the minimum water depth of 28 [m], (s) and having determined the characteristic distance (s_c) and terminal velocity (v_t) for a specific object, the actual impact subsea velocity (v) and thus the impact energy can be calculated using above given 8.

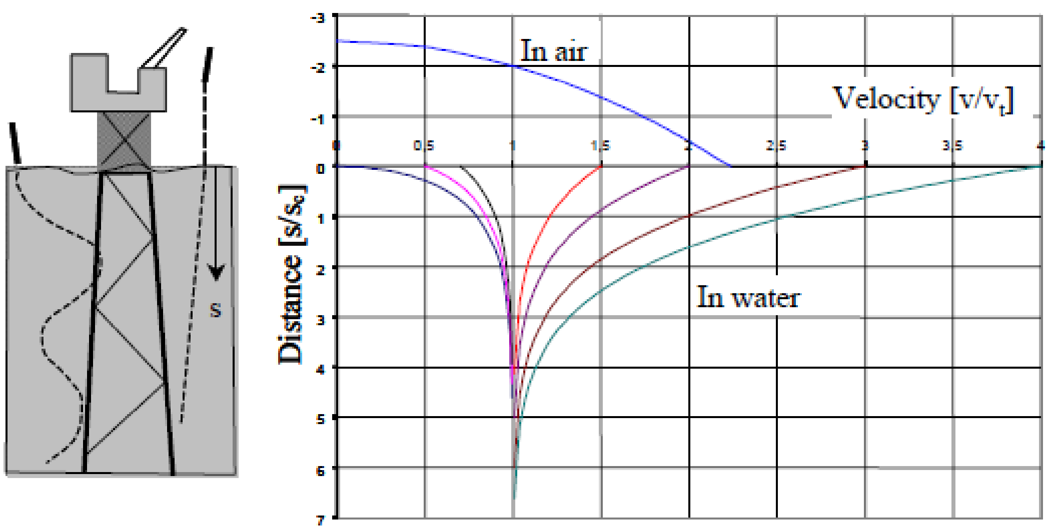


Figure 8, Velocity profile for objects falling in water [12]

Table 17 Kinetic impact energies for design dropped objects

Object	Unit	1	2	3	4	5
Impact vi,a at waterline. Sa=50 m	[m/s]	31.3	31.3	31.3	31.3	31.3
Terminal velocity in water, vt. S=26m	[m/s]	8.98	9.62	10.17	12.5	11.43
Kinetic impact energy, Ek	[kJ]	35.8	65.7	105.8	453.3	1097
Bearing capacity, p(h)	[tonnes/m^2]	41.8	65.7	58.7	108.6	108.2
Absorption energy Rock dump, (Epd)	[kJ]	36.4	65.2	105.0	443.1	1095.5
Absorption energy Rock spool, (Eps)	[kJ]	26.1	26.1	26.1	26.1	26.1
$h_{,critical}$	[m]	**0.24**	**0.28**	**0.32**	**0.65**	**0.43**

It should be noted that the absorption energy of the spool, is not contributing to the total absorption energy. The rockberm should provide all the absorption energy, such that the pipeline is fully protected and not contribution to the absorption.

8.2. Rock dump energy capacity

The properties of the rock dump as presented in Table 6, are used as input for the dropped object calculation.

The bearing force which can be taken by the rock dump is evaluated according the Brinch-Hansen method.

The energy absorption capacity of a rock dump is defined by:

$$E_p = \mathrm{p} \cdot g \cdot \left\{\frac{1}{2} \cdot (B_r + B_o) \cdot \frac{1}{2}(L_r + L_o) \cdot h\right\}$$

Whereas, Br, Lr=breadth/length influence zone rock dump at top of pipe .

$$Br = Bo + 2 \cdot h \cdot \tan(90 - \varphi)$$

$$Lr = Lo + 2 \cdot h \cdot \tan(90 - \varphi)$$

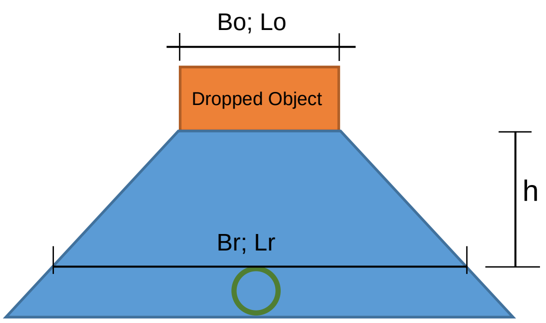


Figure 9 Rock dump geometric annotations

Where both Br and Lr are calculated per object, based on the rock dump properties as provided in Table 6 and the pipe diameter, which is equal to Bo and Lo.

Cylindrical objects will find a stable falling orientation in a horizontal position. As the longest object considered is 1.2 m in length and the width of the rock cover is typically 2 meters, it is assumed that the object contacts the rock cover along its full length. The contact area is then equal to the outer diameter times the length.

The absorption energy calculated for the objects dropped on the and 20" for both the rock dump and the spool is presented in Table 16, where the maximum value for the rock dump cover is highlighted. The absorption energy of the spool is identical to the absorption energy of the pipeline (Ep = 26.1 [kJ]), as calculated in section 7.10.

As can be seen, object 4 is most critical regarding the required rock dump height, above pipeline, which should be more than 0.65 m.

9. Conclusions

Conclusions.

The Eems-Dollard to North Sea area is busy ship traffic area with high ship densities. Generally high ship densities induces higher accidents rates for collision and sinking. Ship accidents result into the higher pipeline risks for dropped and dragging anchors.

The ships frequenting the Eems-Dollard ports are generally smaller ships, as the Eems-Dollard ports cannot receive the very large vessels (max draught approx. 14 m), all larger vessel arrival and departures are controlled by a traffic control centre. And will enter or leave the fairway with the mandatory pilotage and tug boat assistance.

The N05A pipeline has a relative large wall thickness and is for stability purposes provided with a combination of measures like rock berm, CWC and burying. These additional measures provide additional protection against third party interference.

Dropped and dragging anchors

Generally, dropped and dragging anchors are the dominant threat for the pipeline. Just because ships need to navigate in the narrow shipping lane, means that anchors are easily deployed in case of emergency. The minimum soil cover to achieve a failure probability of less than 10^{-6} per km per year is determined.

When no CWC is applied, a minimum burial depth of 0.7 m (ToP) is to be applied in ranges KP 0-2.7 and 8.0-12.7 with high density shipping, 0.3 m of cover is required for the section KP 12.7-14.7, in the remainder between KP2.7-8.0, no cover is required.

With 40 mm of CWC, the burial depth in the designated shipping lanes (KP 0-2.7 and 8.0-12.7) must be 0.6 m, outside the shipping lanes no cover is required in relation to protection of the pipeline against anchors.

Increasing the CWC to 140 mm requires a cover height of 0.5m in the shipping lane. The determined cover for 140 mm CWC in the shipping lane considers an update to NEN 3656, expected to be in effect by the time of pipeline installation, where the cover depth in a shipping lane is based on a risk assessment instead of the minimum requirement of 0.6m cover in the 2015 edition.

The energy absorption capabilities of the CWC referred in this document are just indicative and require confirmation.

Dropped Objects

The pipeline spools near platform N05A , require full protection against dropped objects. This is done by rock berm with a required rock berm height of 0.65 m above the spools.

Fishing gear and sinking ships

Fishing gear interference damage and sinking ships are both relative less critical pipeline risks. The un-buried pipeline case is more exposed but still the risk is below acceptance level.

Consequence of damage

The calculated probabilities are for damage 3 categories. This is a loss of containment of natural gas with a fraction condensate. With the maximum liquid hold-up of approximately 137 m^3 a part of this volume could be released.

A. Risk Investigation and Evaluation

The following attendees have participated in the pipeline RIE, held on 3 December 2019 at One-Dyas office Amsterdam

- Jan Willem in 't Anker   Engineering ManagerONEDyas
- Frits Gremmen   Pipeline EngineerONEDyas
- Michel van der Beek   HSE EngineerONEDyas
- Pascal Ferier   Project ManagerEnersea
- Jan van den Berg   Pipeline EngineerEnersea

Applied Risk Matrix

Risk assessment matrix

Potential consequences									
Harm to People	Environmental Impact	Asset Damage	Reputation Impact		Never heard of in Industry	Heard of in Industry	Has occurred in NL or UK EP Industry	Happens several times per year in NL or UK EP Industry	Happens several times per year in own company
P	E	A	R		A	B	C	D	E
No injuries or health effect	No effect	No damage	No impact	0	Low	Low	Low	Low	Low
Slight injuries not effecting daily life	Slight impact	Slight damage <10K €	Slight impact	1	Low	Low	Low	Low	Low
Minor injuries or health effect, restriction in work or life for 5 days	Minor environmental damage, but self-reversible	Minor damage 10K-100K €	Minor impact	2	Low	Low	Low	Medium	Medium
Major injuries or health effect, lost time or effect for more than 5 days	Limited environmental damage that will persist or needs intervention	Moderate damage 100K-1000K €	Significant regional impact	3	Low	Low	Medium	Medium	High
Permanent total disability or up to 3 fatalities	Severe Environmental damage that will require extensive measures to restore	Major damage 1-10x10⁶ €	Major impact on national reputation	4	Low	Medium	Medium	High	High
More than 3 fatalities	Persistent severe Environmental damage that will lead to loss of use or natural resources over wide area	Massive damage over 10x10⁶ €	Major impact on Companywide reputation	5	Medium	Medium	High	High	High
Score P, E, A, R, on Consequences and Likelihood. The highest score is valid for the registration and investigation. Example an incident with a score for either P,E,A,R in 3E makes it a High for Registration and Investigation					An incident can score different on P,E,A,R. An incident can happen with damage several times per year (score E on Asset), but hardly ever with Environmental damage (score B on Environment)				

RIE Outcome, action list

The following actions were recorded during the workshop					
		Action	**response**	**Action holder**	**Date**
	Design based on faulty metocean and environmental data, or faulty application	Comparison with other locations		OneDyas	
	Installation, tie-in NGT defect	separate evaluation of risk required		OneDyas	
	Liquefaction	ALARP. Can we find similar projects	.. Email 04 dec 2019 to Frits Gremmen	Enersea	
	Scour, loss of cover, exposure (freespan), buoyancy	Captured in MER		OneDyas	
	Dropped and dragging anchor	Contact RWS to investigate legitimacy anchoring zone. ALARP. Assessing effcetiveness of measures.		OneDyas	
	Ship traffic	ALARP. To be performed for platform		OneDyas	
	Dredging waterway	Contact RWS		OneDyas	

B. Risk Register

(3 pages)

Generic Hazard	Specific Hazard	Pipeline section	Cause	Potential Effect	Initial Barriers	Initial Risk S	L	RR	Control / Safeguard	Reference Document	Residual Risk S	L	RR	Action
DFI (design, fabrication and installation errors)														
	Design and material, specifying properties	**general**	Inadequate material properties to meet design requirements	Non-compliance to codes and regulations, delays, costs	Design Standards,	2	C	L	Design review, Verification by Certifier		2	B	L	
	Design and material, fracture control	**general**	Inadequate specified brittle and ductile toughness properties.	Non-compliance to codes and regulations, delays, costs	Design Standards,	2	C	L	Design review, Verification by Certifier		2	B	L	
	Design based on faulty process parameters	**general**	Process parameters and conditions are unconfirmed, not consistent	Non-compliance to codes and regulations, delays, costs	Design Standards,	2	C	L	Design (peer) review, Verification by Certifier		2	B	L	
	Design based on faulty metocean and environmental data, or faulty application	**general**	The water depth varies from 26.5 to 9.5 m with significant stability issue. Poor geotechnical interpretations	Pipeline stability at risk. Non-compliance to codes and regulations, delays, costs.	Design Standards, Design focusses specifically on stability, metocean data.	3	C	M	Design (peer) review, Verification by Certifier,		3	B	L	
	Design and material defects, design life	**general**	Fatigue, corrosion rates, material degradation.	Anticipated design life is not met. Non-compliance to codes and regulations, delays, costs.	Design Standards. Design incorporates fatigue life, corrosion rate, degradation predictions.	2	C	L	Design review, Verification by Certifier.		2	B	L	
	Fabrication material defects, wrong properties of materials	**general**	Manufacturing defects, inadequate material inspection and test procedures	Non-compliance to codes and regulations/company specs, delays, costs	Design Standards, QA/QC policy, Company Standards.	2	C	L	Inspection and Supervision		2	B	L	
	Installation, construction defects		Installation defects	Pipeline buckle, dents, any type of damage. Causing delays and costs.	Design Standards, installation design and procedures, QA/QC policy	2	C	L	Inspection and Supervision		2	B	L	
Buried	**Installation** trenching problem	**pipeline**	inadequate trench depth, boulders in trench, UHB risk, suitability of soil	Non-compliance to required burial depth, delays, costs	Design Standards, QA/QC policy, Site surveys: seabed objects, likeboulders, wrecks and magnetic objects are surveyed and incorpated in the routing design.	3	C	M	Perform trenching and installation feasibility determining suitable installation equipment.		3	B	L	
Unburied	**Installation** stability problem	**pipeline**	Insufficient submerged weight (steel wall thickness and / or CWC)	Non-compliance to stability requirements, delays, costs	Design Standards, QA/QC policy, Soil surveys and metocean data.	3	B	L			3	B	L	
	Installation (environmental restrictions)	**pipeline**	Unforeseen limitations	Delay and cost	Pipeline is part of the environmental assessment (MER)	2	C	L	Follow-up on MER outcome		2	C	L	
	Installation clash, error	**at platform**	Unforeseen SIMPOS, Loss of control, colission with platform, workover rig, Target box too close to platform. Magnetic contacts close to platform.	Delay, costs, safety	Planning, interface management. Design incorporates potential clashes or avoids obstacles.	3	D	M	Managing stakeholder and interfaces. Perform installation feasibility Manage contracts and installation contractor windows, to avoid clashes.		3	C	M	
	Installation, tie-in NGT defect	**at NGT Tie-in**	Not able to establish tie-in. Unforeseen issues, eg Reduced wall thickness at Hot tap location, etc.	Non-compliance to installation specs, delays, costs, loss of containment.	Planning, interface management.	5	C	H	Managing stakeholder and interfaces. Perform feasibility study. Will be executed by NGT. To be managed by contracting reputable contractor and will be risk assessed separately.		5	B	M	Separate evaluation of risk required
	Pre-commissioning error		Any failure related to pre-commission the pipeline. Inadequate cleaning and drying	Non-compliance, delays, costs.	Design Standards, QA/QC policy	2	C	L	Inspection and Supervision, as-laid information		2	B	L	
Natural Event/Hazards														
	Land slide, debris flow	**general**	Soil and slope instability. Not captured in geotech reports	pipeline rupture, pipeline large displacements, resulting in buckling and loss of containment	Geotech data interpreted and no significant exposure found	2	C	L	PIMS, perform event-based inspection. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)		2	C	L	
	Seismic loading, fault lines	**general**	Seismic and fault movement	pipeline overstress, buckling resulting in loss of containment	Geotech data interpreted and no known seismic risks found	2	C	L	PIMS, perform event-based inspection		2	C	L	
	Subsidence	**platform**	Subsidence due to well drilling, historic sand extraction	unforeseen pipeline displacements, resulting in buckling and loss of containment	Geotech data interpreted and no subsidence expected	2	C	L	PIMS, perform event-based inspection. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)		2	C	L	
Buried	Liquefaction	**pipeline**	Wave induced liquefaction	Floatation of pipeline, resulting in buckling. Interruption production	Trench right back-fill material. Apply high specific gravity.	3	C	M	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar). Perform trenching and backfill analyses. Remedial works (re-trenching, backfilling e.g. rock dumping)		3	C	M	ALARP

Generic Hazard	Specific Hazard	Pipeline section	Cause	Potential Effect	Initial Barriers	Initial Risk S	L	RR	Control / Safeguard	Reference Document	Residual Risk S	L	RR	Action
Buried	Uncontrolled Pipeline movement (vertical)	**pipeline**	Loss of cover, Loss of stability	Overstress, buckling, resulting in loss of containment	Design standards. Trenching providing controlled pipeline stability. Depth of cover.	3	C	M	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI), pipe tracking and seabed scanning (e.g. multibeam sonar). Perform trenching and backfill analyses. Remedial works (e.g. rock dumping)		3	B	L	
Un-buried	Uncontrolled Pipeline movement (vertical, lateral)	**pipeline**	Loss of stability	Excessive displacement, Overstress, buckling, resulting in loss of containment	Design standards. Concrete Weight coating =140 mm,	3	C	M	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar). Perform state-of-art stability analyses . Remedial works (e.g. rock dumping)		3	B	L	
Un-buried	Scour, loss of cover, exposure (free span), buoyancy	**pipeline**	Mobility of seabed	Developing free spans resulting in overstress, fatigue, hooking of fishing gear, excessive displacements	Design standards.	3	C	M	PIMS, perform inspections. Seek geotechnical/hydro-morphological advise. Remedial works (e.g. rock dumping)		3	B	L	MER states a requirement for morphological study
	Severe weather	**pipeline**	Unpredicted severe weather conditions	Any damage	Sufficient knowledge of weather and environmental data	2	C	L	PIMS, perform event-based inspection.		2	C	L	
Third party damage/interference														
	Dropped objects	**near platform**	Dropped Object from vessel/rig/platform	Damaging coating and pipeline. Dent, Loss of containment. (effect can extend to platform)	The rock berm is designed for full protection against dropped objects (and rig anchors) on spools. Lifting activities at North end of platform	3	D	M	PIMS, maintaining procedures for lifting, approaches and position of vessels and dril rig. Periodically visual inspect rock berm/protection or sidescan sonar. Remedial works (e.g. rock dumping). Procedure for platform abandonment.	Risk assessment study capturing dropped objects	3	B	L	
buried	Dropped and dragging anchor	**pipeline**	Dropped/dragging anchor Pipeline route crosses anchor zone.	Damaging coating and pipeline. Damage to pipeline, rupture. Loss of containment	Trenching and large diameter reduces risk of hooking. Depth of cover = 1m.	4	D	H	PIMS, periodic pipe tracking survey and active AIS monitoring. Regulations in fairway for marine traffic on Eems (pilotage and tug assistance). Remedial works (e.g. rock dumping). Regulatory restriction for anchoring outside designated anchor zones.	Risk assessment study capturing dropped and dragging anchors	4	C	M	Contact RWS to investigate legitimacy anchoring zone. ALARP. Assessing effcetiveness of measures.
un-buried	Dropped and dragging anchor	**pipeline**	Dropped/dragging. Pipeline route crosses anchor zone.	Damaging coating and pipeline. Damage to pipeline, rupture. Loss of containment	Concrete weight coating (CWC=140 mm) reduces some impact of denting or hooking.	4	D	H	PIMS, periodic pipe tracking survey and active AIS monitoring. Regulations in fairway for marine traffic on Eems (pilotage and tug assistance). Remedial works (e.g. rock dumping). Regulatory restriction for anchoring outside designated anchor zones.	Risk assessment study capturing dropped and dragging anchors	4	C	M	Contact RWS to investigate legitimacy anchoring zone. ALARP. Assessing effcetiveness of measures.
buried	Foundering, ship sinking	**pipeline (shallow section)**	Sinking, stranding ship	damage to pipeline, likely only buckling	Trenching provide some minor protection	3	C	M	PIMS, and active AIS monitoring. Regulation for marine traffic on Eems (piloting and towing service (mandatory DWT >10.000)). Safeguard pipeline. Remedial works (e.g. rock dumping)	Risk assessment study capturing sinking ships	3	B	L	
unburied	Foundering, ship sinking	**pipeline (shallow section)**	Sinking, stranding ship	damage to pipeline, likely only buckling		3	C	M	PIMS, and active AIS monitoring. Regulation for marine traffic on Eems (piloting and towing service (mandatory DWT >10.000)). Safeguard pipeline. Remedial works (e.g. rock dumping)	Risk assessment study capturing sinking ships	3	B	L	
*buried **/unburied***	Dropped and dragging anchor	**riser**	Main cause are drifted ships from main shipping lane	Colission with platform, damaging riser. Damage to riser, loss of containment	Platform is projected near shipping lanes. Riser(s) situated within jacket	5	C	H	Managing exclusion zone, Navigation Aids, Active AIS monitoring with possibility to warn off ships, Subsea check valve near platform, platform abandonment procedure	32287-1-MO, Platform collision report	5	B	M	ALARP. To be performed for platform
buried	Fishing gear	**pipeline**	pulling and hooking of pipeline	Damage to pipeline, dents, displacements	Trenching provides adequate protection against fishing gear	2	B	L	PIMS. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)		2	B	L	
unburied	Fishing gear	**pipeline**	pulling and hooking of pipeline	Damage to pipeline, dents, displacements	Concrete weight coating = 140 mm. CWC provide protection against denting. (CWC damage)	2	C	L	PIMS. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)	Risk assessment study capturing fishing interaction	2	B	L	
buried/unburied	Unexploded ordinance	**pipeline**	undetected UXO	damage to pipeline, loss of containment	Surveys contain magnetic anomalies and safety distance of 200 m is kept.	2	C	L	PIMS. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)		2	B	L	
buried/unburied	Wrecks, boulders and obstructions	**pipeline**	Presence of anomalies.	Potential clash and damage to pipeline, non-compliance (ecological/archeological values)	Ship wrecks and other objects are identified and separation distances are maintained	2	C	L	PIMS. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar)	N05A-7-51-0-72510-01-01_Overall field layout drawing	2	B	L	
buried/unburied	Mining, sand extraction, dredging	**pipeline**	Mining, sand extraction or dredging activities.	Potential clash and damage to pipeline	No clashes are foreseen	2	C	L	Stakeholder and right of way management. PIMS, perform inspections		2	B	L	
buried/unburied	Dredging waterway	**pipeline vaargeul**	Future extension of port entrance, with dredging fairway	Non-compliance, loss of license to operate	Obtain and implement permit conditions for crossing fairway/shipping channel extention.	4	C	M	PIMS, Stakeholder and right of way management. Manage permits.	N05A-7-51-0-72510-01-01_Overall field layout drawing	4	B	M	Contact RWS
buried/unburied	Sabotage	**general**	Sabotage	damage to pipeline		2	C	L			2	C	L	
	Pipeline (future) crossing(s)	**pipeline**	unfavourable design	Additional/excessive loading onto pipeline system.	Design standards.	2	C	L	PIMS, Stakeholder and right of way management		2	B	L	
Corrosion														
	Internal corrosion	**general**	Changing composition of Production fluids. Water dewpoint too high	Higher corrosion rate than anticipated, not meeting service life, resulting in loss of containment	CA= 3mm, no corrosion is expected (treated and dew pointed fluids)	2	C	L	PIMS, perform inspections and monitoring. Periodic wall thickness measurements. Monitoring fluid properties , spec water content and dew point, inhibition rate.		2	B	L	

Generic Hazard	Specific Hazard	Pipeline section	Cause	Potential Effect	Initial Barriers	Initial Risk			Control / Safeguard	Reference Document	Residual Risk			Action
						S	L	RR			S	L	RR	
	Internal corrosion	general	Inadequate inhibition.	Inhibition not adequate result in higher corrosion rate than anticipated, not meeting service life	CA= 3mm	2	C	L	PIMS, perform inspections and monitoring. Monitoring fluid properties inhibition rate and periodic inhibition efficiency control.		2	B	L	
	Galvanic corrosion	general	Different materials in pipeline system.	Local corrosion near material changes, resulting in loss of containment	Transition by isolation between different metals.	2	C	L	PIMS, perform inspections and monitoring		2	B	L	
	External corrosion (coating damage)	pipeline	Coating damage (due to e.g. dropped objects, dragging anchors)	Local corrosion, resulting in loss of containment	CA= 3mm, 3LPE coating with anodes	3	C	M	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and CP stabbing.		3	B	L	
	External corrosion (coating damage)	riser	Coating damage (due to e.g. dropped objects, vessel impact)	High corrosion rate in splash zone, due to oxygen and seawater, resulting in loss of containment	CA= 3mm, neoprene (extra mechanical strength) in splash zone	2	C	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and CP stabbing.		2	B	L	
	External corrosion (CP failure)	general	Anode depletion, faulty contacts	Too low protection levels resulting in external corrosion, resulting in loss of containment	Anode design includes contingency.	2	C	L	PIMS, perform inspections and monitoring		2	B	L	
	Erosion	general	particles in production fluid	Loss of wall thickness, resulting in loss of containment	Design standards. CA= 3mm, sand particles and high fluid velocities are not foreseen. Peer review.	2	C	L	PIMS, perform inspections and monitoring . Wall thickness measurements and fluid properties (velocity and sand particles).	TR-19018-ONE002 FA Steady state analysis CRS Flow Assurance N05A Steady State PEER Review	2	B	L	
	Fatigue	pipeline	Unforeseen fatigue, free spans,	Cracking in material, resulting in loss of containment	Design standards. Fatigues analyses to be performed and acceptable span lengths determined.	2	C	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and side scan sonar		2	B	L	
	Fatigue	riser	Unforeseen fatigue, loose clamps/guides	Cracking in material, resulting in loss of containment	Design standards. Fatigues analyses to be performed.	2	C	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI).		2	B	L	
	Brittle fracture	general	During Cold-start-up or changing operation modes.	Brittle fracture results in rupture and loss of containment	Min. material design temperature set at - 20 C for Charpy value.	2	C	L	PIMS, monitoring operation modes. Procedures for changing operation modes (incl cold-starts)	TR-19018-ONE002 FA Steady state analysis CRS Flow Assurance N05A Steady State PEER Review	2	B	L	
Structural Threats														
	Uncontrolled riser movement	riser	Loss of clamp or guiding	Overloading, non-compliance to codes and regulations, loss of containment	Captured in design	3	C	M	PIMS, Procedures for monitoring and periodic inspections (specific for clamping). Visual inspections and incorporate (top rope) inspection of riser clamp tightness during platform inspection. Procedures for monitoring and periodic inspections (specific for clamping).		3	B		
	Excessive riser displacement / loads	general	Excessive temperature or pressure.	Overloading, non-compliance to operating design envelopes	Captured in design, spools take the expansion	2	B	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar). Monitor and analyse temperature and pressure excursion.		2	B	L	
	On bottom stability	general	Any cause. Malfunction of CWC	Large displacements, Overloading or buckling, non-compliant	Captured in design, pipeline is buried	2	B	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar).		2	B	L	
	Static Overload	general	Any cause. Excessive rockdump.	Overloading, non-compliance to design envelopes, loss of containment	Captured in design	2	B	L	PIMS, perform inspections. Periodic visual inspection subsea (general visual inspection (GVI) and seabed scanning (e.g. multibeam sonar).		2	B	L	
	Fatigue	general	Any cause. Excessive spans, scour.	Overloading, non-compliance to design envelopes, cracking, rupture. Loss of containment.	Captured in design	2	B	L	PIMS, perform inspections , Monitor and analyse pressure and temp cycles.		2	B	L	
Operational & Process errors														
	Export to NGT	general	Compliance or contractual issue	Non-compliance/non-conformity to agreements, problem with exporting gas	Implement contracting conditions	2	C	L	PIMS, Contract and stakeholder management. Develop procedure for periodic exchange of data.		2	B	L	
	Export to NGT	general	Off-spec gas, fluid in N05A pipeline.	Non-compliance/non-conformity to technical requirements	Defined export fluid properties	2	C	L	PIMS, Monitor fluids and develop off-spec fluid procedure. Assure that process envelopes are set in systems (DCS)		2	B	L	
	Process envelope	general	Process conditions (and operationing outside envelope)	Non-compliance/non-conformity to agreed process envelopes, higher corrosion rates than foreseen, hydrate blockage. Loss of containment	Defined process and operating conditions	3	C	M	PIMS, Monitor fluids and inhibition. Maintain operations procedures for applicable operation modes. Assure that process envelopes are set in systems (DCS)	TR-19018-ONE002 FA Steady state analysis. CRS Flow Assurance N05A Steady State PEER Review	3	B	L	
	Process parameters envelope	general	Exceeding design pressure (DP = 111 barg) and temperatures (DT = - 20 and 50 C)	non-compliance to design parameters, overstress, larger displacement than foreseen. Loss of containment	Defined process and operating conditions	2	C	L	PIMS, Monitor fluids and procedure. Maintain operations procedures. Assure that process envelopes are set in systems (DCS)		2	B	L	
	Operator errors	general	Unable to follow or inadequate procedures and systems of work	High risk, high costs and safety threat	Established operator	3	C	M	PIMS. Operational company standards & systems. Periodic check and update procedures, check lessons learned		3	B	L	
	Operator errors	pipeline	Inadequate and Incorrect IRM	High risk, high cost and safety threat	Established operator	3	C	M	PIMS. Operational company standards & systems. Periodic check and update procedures, check lessons learned		3	B	L	

C. Reference graphs for dropped and dragging anchors

Data was gathered on several types of anchor configurations (stockless and Baldt) in a mass range of 550 to 15400 kg. The length and width dimension projected to the oncoming flow during the descend to the sea floor were obtained. A polynomial curve has been fitted through the data and this was used to estimate the dimensions of an anchor for which only the mass was specified.

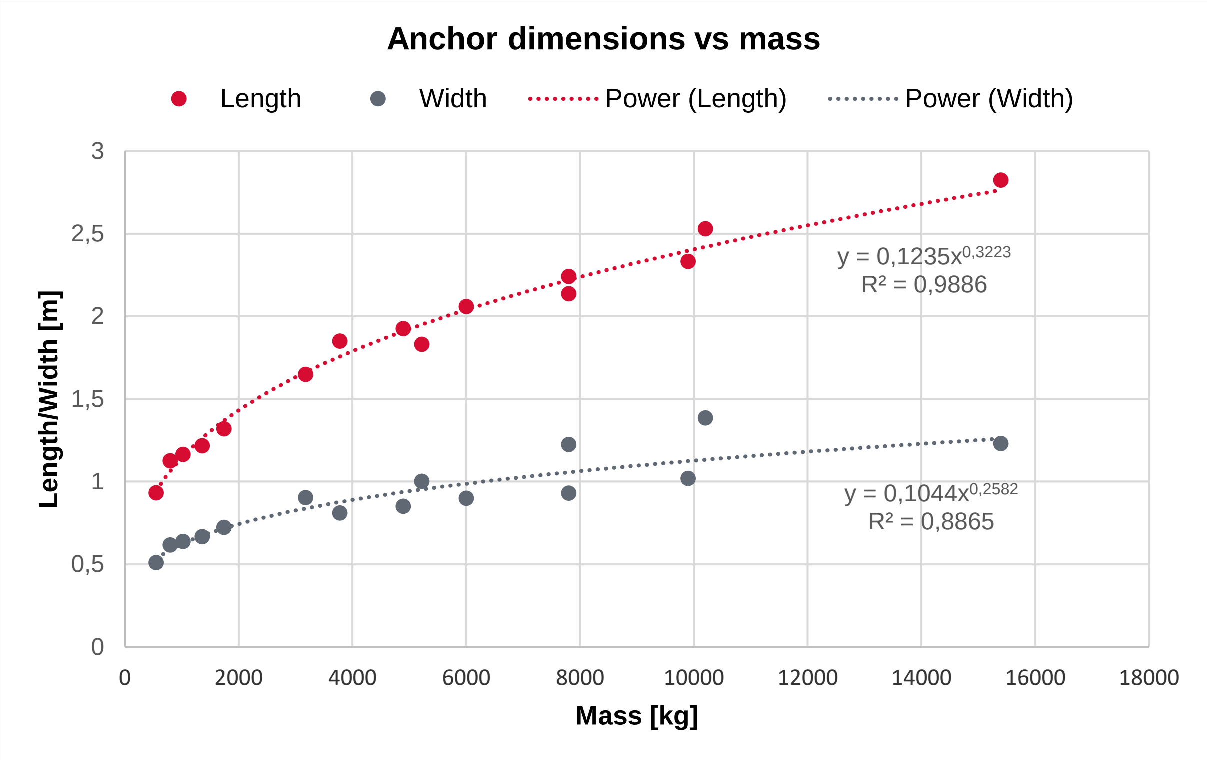


Figure 7, anchor size determination.

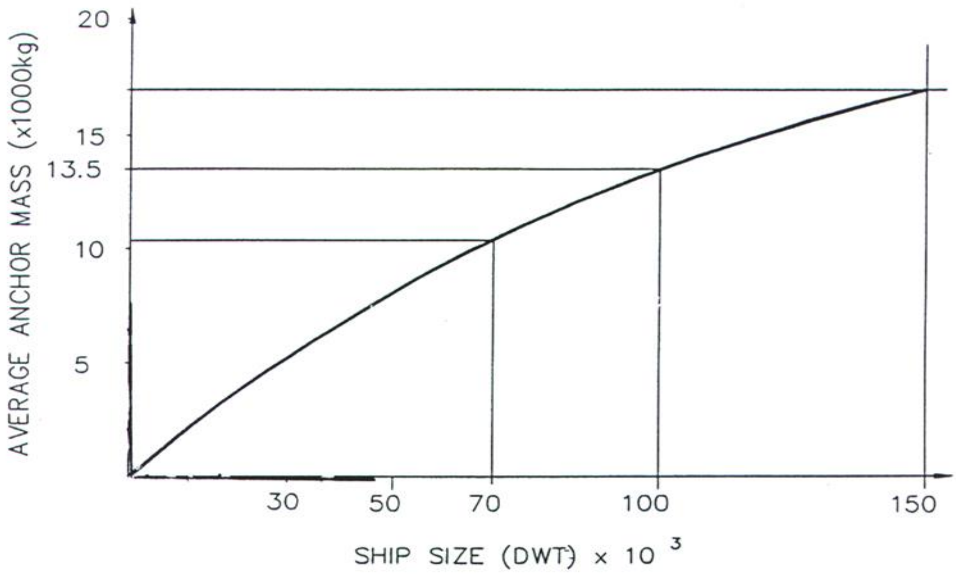


Figure 8, A.Ship size versus anchor mass

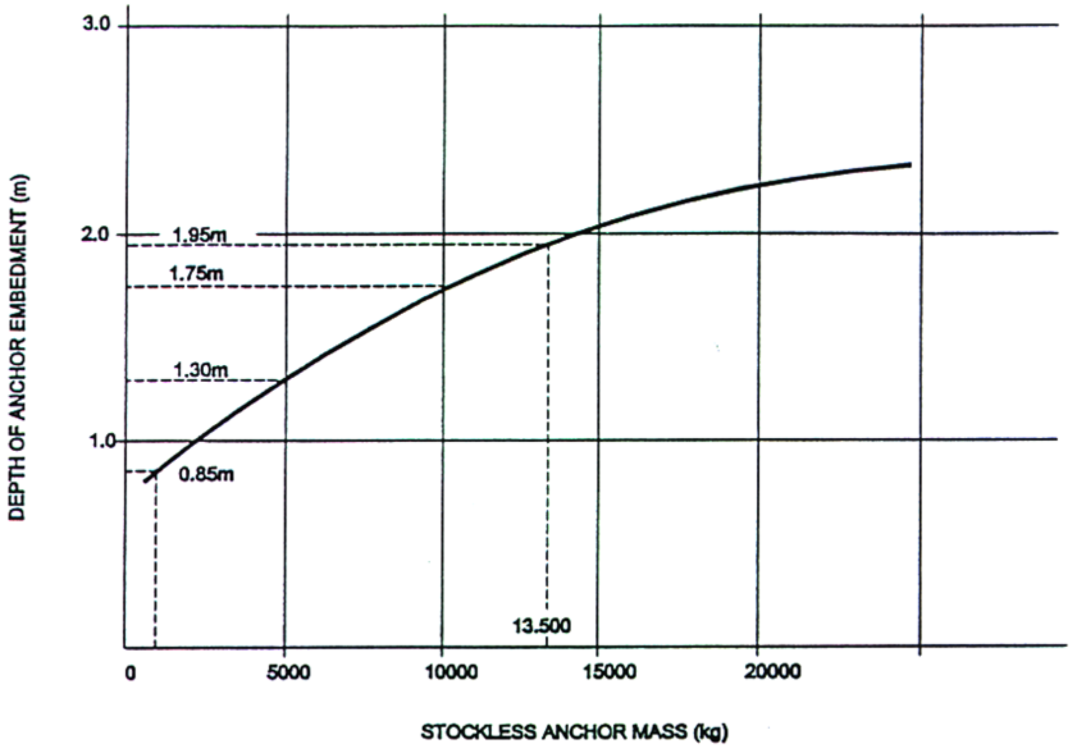
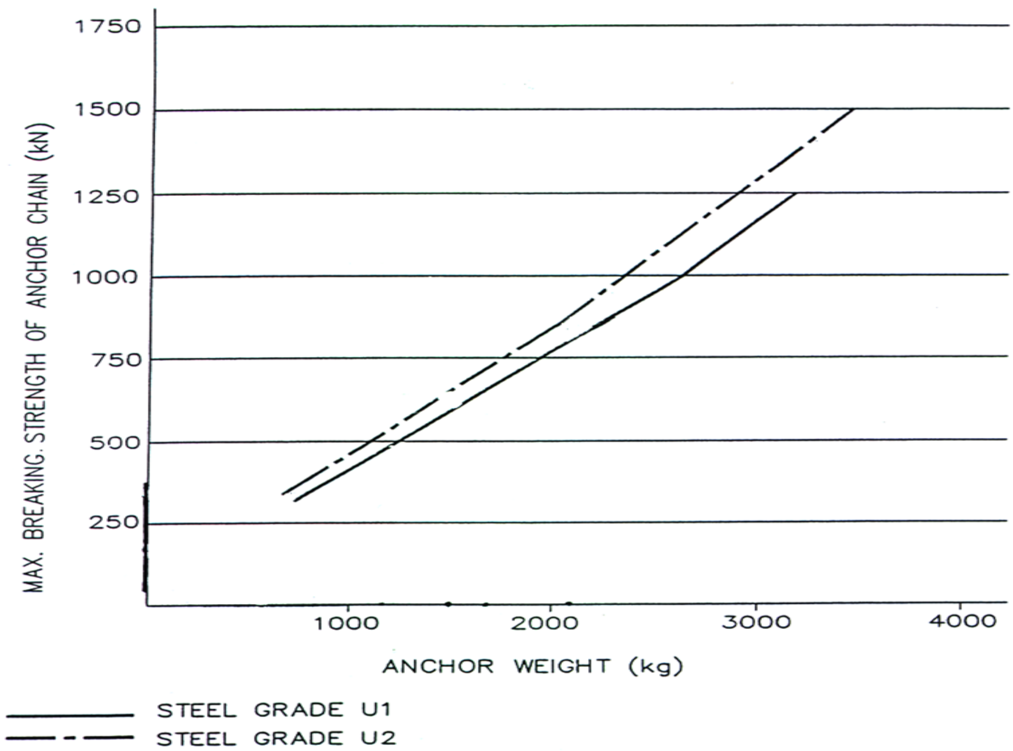


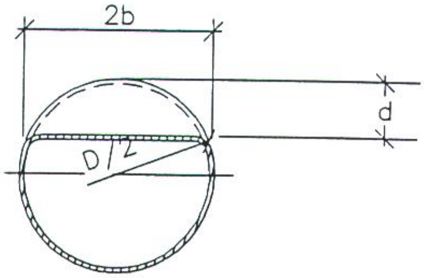
Figure 9, A.Penetration depths due to anchor drag versus anchor size



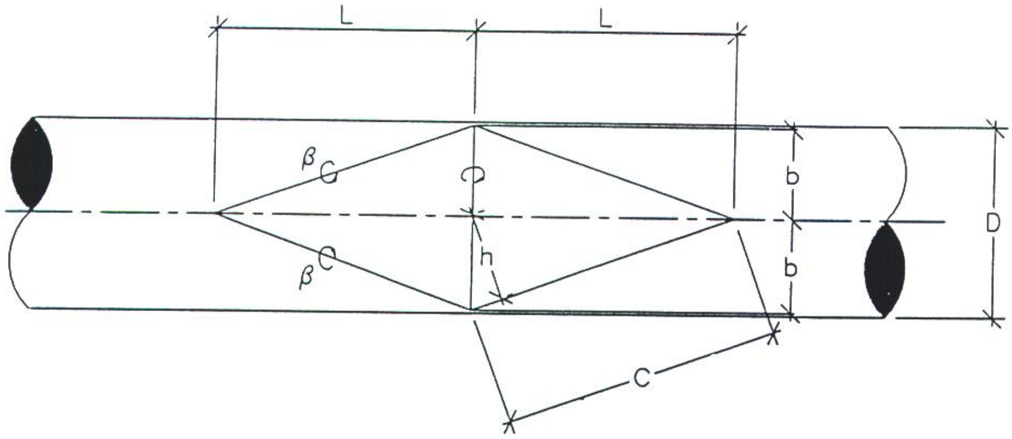
SOURCE: LLOYD'S "REGISTER OF SHIPS"

Figure 10, A.Anchor mass versus maximum breaking strength of anchor chain

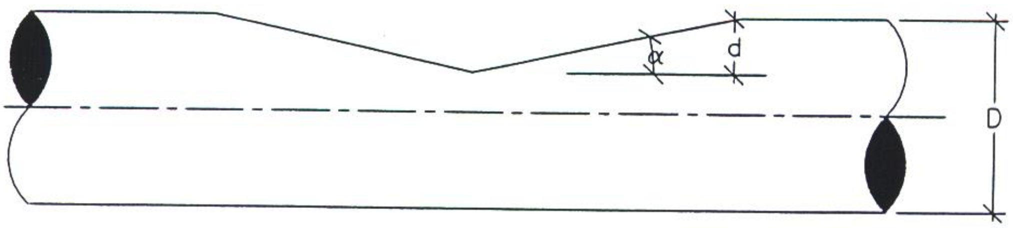
D. Plastic deformation model



A. PIPE CROSS–SECTION THROUGH DENT



B. PLAN VIEW OF SIMPLIFIED DENT SHAPE



C. SIDE VIEW OF SIMPLIFIED DENT SHAPE

$\tan\alpha = d/L$
$\tan\beta = d/h$

E. Dropped anchor calculations

The following calculations were performed for the no CWC situation

Table 18, Kinetic energy calculation per anchor mass group

Symbol	Description	unit	Anchor 1	Anchor 2	Anchor 3	Anchor 4	Anchor 5
g	grav. Acceleration	m/s^2	9,81	9,81	9,81	9,81	9,81
M	anchor mass	kg	1100	2000	4500	10000	15000
w	width frontal	m	0.64	0.74	0.92	1.13	1.25
L	length frontal	m	1.18	1.43	1.86	2.40	2.74
A	anchor frontal area	m2	0.75	1.06	1.70	2.71	3.43
V anchor	anchor volume	m3	0.14	0.25	0.57	1.27	1.91
vt	Terminal velocity	m/s	5.90	6.25	7.41	8.77	9.54
Ma	added mass	kg	143.63	261.15	587.58	1305.73	1958.60
Ek	kinetic energy total	kJ	21.6	44.2	139.8	434.3	772.3

Table 19, Calculation of the absorption energy as a function of the burial depth

Symbol	Description	unit	Anchor mass 1	Anchor mass 2	Anchor mass 3	Anchor mass 4	Anchor mass 5
Nq	Bearing capacity factor	[-]	14.72	14.72	14.72	14.72	14.72
Nc	Bearing capacity factor	[-]	25.80	25.80	25.80	25.80	25.80
Sc	Shape factor	[-]	1.27	1.37	1.46	1.57	1.63
Ng	Bearing capacity factor	[-]	10.94	10.94	10.94	10.94	10.94
Fy (z)	Force at sea bed (z=0,0m)	[N]	1.75E+04	4.13E+04	1.06E+05	2.67E+05	4.28E+05
Epen (z)	kinetic energy absorbed (z=0.0m)	[kJ]	3.49	8.25	21.15	53.46	85.61
	kinetic energy absorbed (z=0.2m)	[kJ]	12.13	24.08	54.92	128.10	198.90
	kinetic energy absorbed (z=0.4m)	[kJ]	25.91	47.49	101.31	223.90	339.89
	kinetic energy absorbed (z=0.6m)	[kJ]	44.83	78.48	160.32	340.88	508.56
	kinetic energy absorbed (z=0.8m)	[kJ]	68.90	117.05	231.94	479.03	704.92

Cover depth	Anchor mass	Critical DWT	P > Cr.DWT	Prob. Drop anchor
[m]	[kg]			x 10^{-6}
0.0	1000	4870	41.9	0.39
0.2	1300	6388	35.3	0.33
0.4	2000	10032	19.7	0.18
0.6	3500	18321	18.0	0.17
0.8	7500	44278	12.8	0.12
1.0	13000	95040	2.5	0.01

Notes:

- Z is the penetration depth and is assumed the thickness of backfill material in the trench.
- A 15% dent requires 20.16 kJ of energy
- The probability in the above table is determined for 15 ships per 1000 km2, the relationship between probability and traffic density is linear.

F. Anchor drag calculations

Table 20, Critical anchor weight as a function of the ToP cover

Cover depth [m]	z [m]	z/D [-]	Nq [-]	Qu [N/m^2]	R [N/m]	Mp [N/m]	F [N]	F [kN]	T=K*F [kN]	Tbreaking (Tb=T) [kN]	Anchor weight [kg]	Crit. DWT [kg]	P>Cr.DWT [%]	Prob drag anchor x 10^{-6}
0.0	0.254	0.5	4.80	10156	5159	1.50E+06	3.52E+05	352	457	457	1097	5358	39.8%	0.64
0.2	0.454	0.9	5.15	19509	9910	1.50E+06	4.87E+05	487	633	633	1520	7520	30.4%	0.49
0.4	0.654	1.3	5.51	30056	15269	1.50E+06	6.05E+05	605	786	786	1887	9435	22.1%	0.35
0.6	0.854	1.7	5.87	41799	21234	1.50E+06	7.13E+05	713	927	927	2226	11235	19.5%	0.31
0.8	1.054	2.1	6.21	54579	27726	1.50E+06	8.15E+05	815	1060	1060	2543	12955	19.1%	0.31
1.0	1.254	2.5	6.47	67694	34389	1.50E+06	9.08E+05	908	1180	1180	2832	14547	18.8%	0.30

G. Platform approach

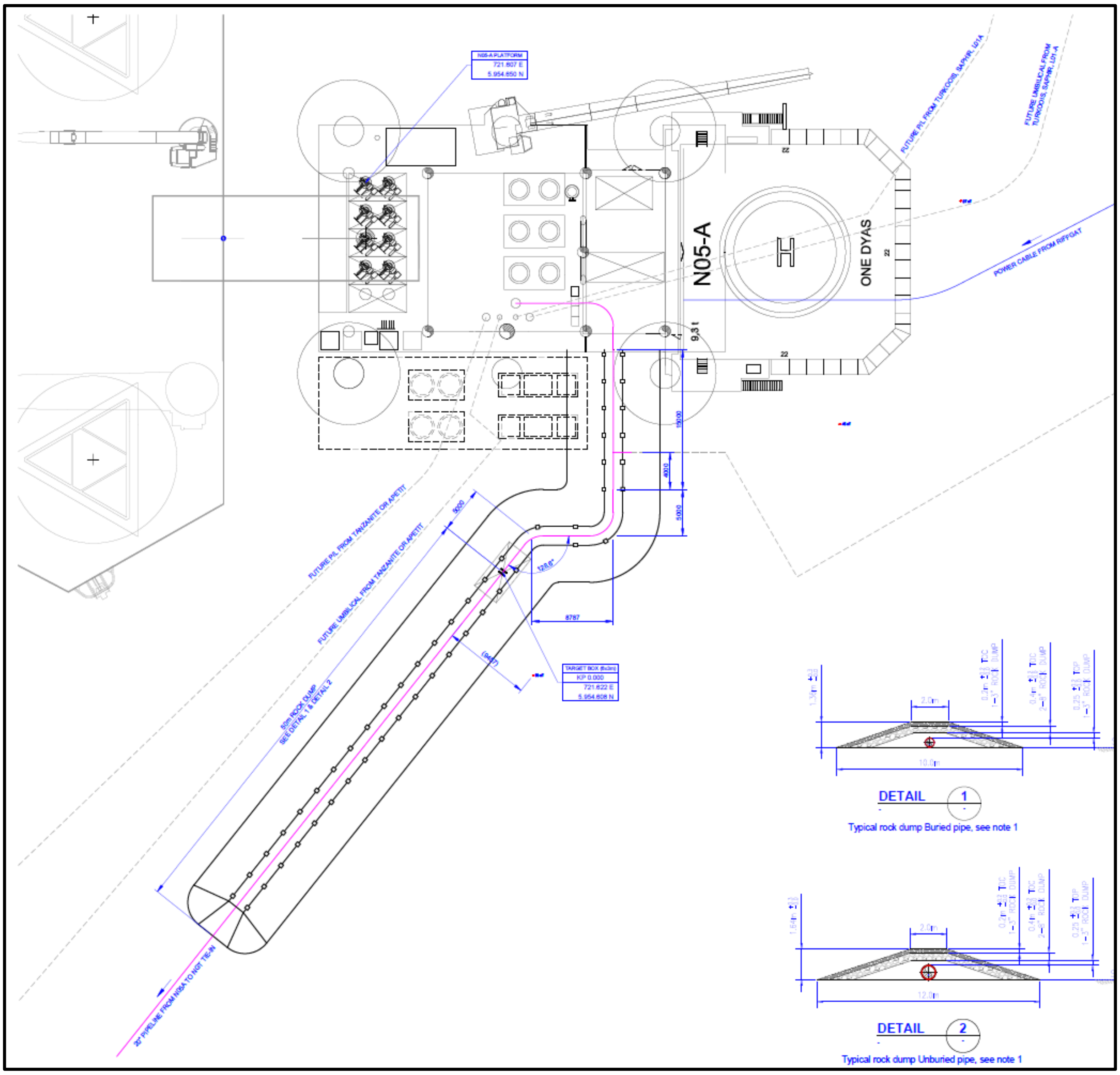


Figure 11, N05A-7-50-0-72019-01, Approach at N05A,

INTECSEA
WorleyParsons Group

Memorandum

DATE	10 October 2019
TO	Frits.Gremmen (ONE-Dyas), Jan Willem in't Anker (ONE-Dyas)
FROM	Erik Koolstra
COPY	Jeroen Timmermans, VanChuong Ha
PROJECT	N05A Pipeline On-bottom Stability Check
SUBJECT	Pipeline stability
DOC NO	416010-00210-EM-001 **REV** B

1 Introduction

ONE Dyas BV is performing design activities for a new pipeline from the future N05A platform to a tie-in to the NGT pipeline. ONE Dyas has requested INTECSEA to perform independent confirmation of the stability requirements for the pipeline. Based on the input provided by ONE Dyas, INTECSEA has assessed the stability requirements for the pipeline section near N05A, and this technical note provides the determined results to ONE Dyas for their comparison with in-house determined values. ONE Dyas prefers to not bury the pipeline and therefore the operational design case is governing for stability design.

2 Basis of Analysis

The input parameters and values that form the basis for this analysis are presented in **Table 1**, and are extracted from the N5-NGT Route option 1 drawing, the metocean design criteria report for N05A and the Survey report N5A to NGT Hot tap, see Ref. [1] to Ref. [3].

Table 1 Input for Stability Design

Parameter	Value
Outside Diameter, inch	16 / 20 / 24
Wall thickness, assumed Sch 60, mm [1)]	16.7 / 20.6 / 24.6
Pipe heading rel to North, deg	From 20° to 200°
Anti-corrosion coating, assumed 3LPP/ 3LPE, mm	3 (@ 950 kg/m^3)

Concrete density, kg/m^3	3300
Content density, assumed, kg/m^3	50
Marine growth, assumed	None
Wave data, H_s, m / Tp, sec [2)] - 100 year return period - 10 year return period - 1 year return period	 9.9 / 14.9 8.4 / 13.8 6.5 / 12.4
Current, near bed value, m/s [3)] - 100 year return period - 10 year return period - 1 year return period	 0.96 0.84 0.74
Water depth for design, m (max depth near platform 26.4 m LAT, minimum 9.8 m LAT near tie-in)	25
Soil type	Fine to coarse sand
Notes: 1) Assumed there is no corrosion allowance on the wall thickness 2) The highest waves approach from direction North-West, this is also near perpendicular to the pipe heading and thus governing for stability design 3) The highest currents are going towards East, this is also close to perpendicular to the pipe	

The environmental data is valid for the platform location and the local water depth (26 to 27 m LAT). Some of the source data is obtained at a water depth of 16 m LAT and converted to values for the platform location depth. Considering the fact that water depth at the NGT tie-in is notably less than at the platform location and the fact that the approach of a complex coast line will significantly affect the design wave and current parameters, it is considered of great value to the project if environmental data is developed for the tie-in location and an intermediate point. For the intermediate point the source data at 16 m water depth could be the basis.

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3 Calculation Results

The calculated results are presented in **Table 2**.

Table 2 Required Concrete Weight Coating Thickness per DNV RP F109

Design condition	Required CWC, mm	
	16 – inch	24 – inch
Absolute stability	>> 500	>>500
0.5 OD displ	450	425
6 a 8 OD displ	200	180
10 OD displ	170	160

For the first kilometre of pipeline (from N05A; KP 0 to KP 1) and from approximately KP 6 to the tie-in with NGT (KP 14.3), it is not recommended to allow significant lateral displacements, for various reasons; tie-in to fixed structure, crossings with existing infrastructure or the crossing of nature areas. Absolute stability or very small lateral displacements under the maximum design load would result in unrealistic concrete weight coating thicknesses when calculated in accordance with DNVGL-RP-F109. Achievable weight coating thicknesses are associated with maximum allowable lateral displacements of 10 OD or more.

To get confirmation for the high values determined with DNVGL-RP-F109, additional calculations have been performed. The results of a "traditional Morrison equation" based analysis and PRCI software (previously AGA software) analysis are shown in **Table 3**.

Table 3 Required Concrete Weight Coating Thickness - Additional analysis results

Design condition	Required CWC, mm	
	16 - inch	24 – inch
Traditional Morison-equation analysis 1)	210	200
PRCI level 2 2)	150 a 175	150 a 175
Notes: 1) This type of analysis does not provide information about likely lateral displacements 2) This thickness fulfils the Level 2 requirements but requires Level 3 (dynamic stability) analysis confirmation and determination of lateral displacements that can be expected for this weight coating thickness.		

It is not considered economical to increase the steel wall thickness to a value that would result in a more feasible concrete weight coating thickness with the DNVGL-RP-F109 method. Trenching is likely the more economical solution. When looking at it from an environmental point of view; trenching in a Natura 2000 area may not be desirable and complicate permitting, however, the environmental effects of one-time trenching (post installation narrow trench) should be evaluated against large lateral pipeline displacements over the seabed during the design life.

Another consideration is the evidence for a dynamic seabed (NGT self-burial, ripple forms and small dunes). A dynamic seabed could result in future self-burial, span development, future exposure of actively buried sections, etc. This could be a reason, as an example; to design for lower design loads, such as 50- or 10-year return period data and determine in the 2 to 5 years after installation if active trenching is required to ensure long term stability.

Finally, design criteria and philosophy as well as developments since installation of the NGT pipe section where the tie-in is planned can be of great value in making design decisions for the N05A pipeline.

4 References

Ref. [1] Noordgastransport NGT, N5 – NGT – Route option 1, 27/03/2019

Ref. [2] Fugro, Final report, Metocean criteria for the N05A platform, 181892_1_R1, 22 May 2019

Ref. [3] Geo XYZ offshore, N5A Development, N05A-7-10-0-70017-01, Rev 1, 14-06-2019

N05A Development Project

Pipeline Trenching Options

DOCUMENT NUMBER:

N05A-7-10-0-70038-01

Rev.	Date	Description	Originator	Checker	Approver
00	19-12-2019	For internal review	FGR	JWA	JWA

TABLE OF CONTENTS:

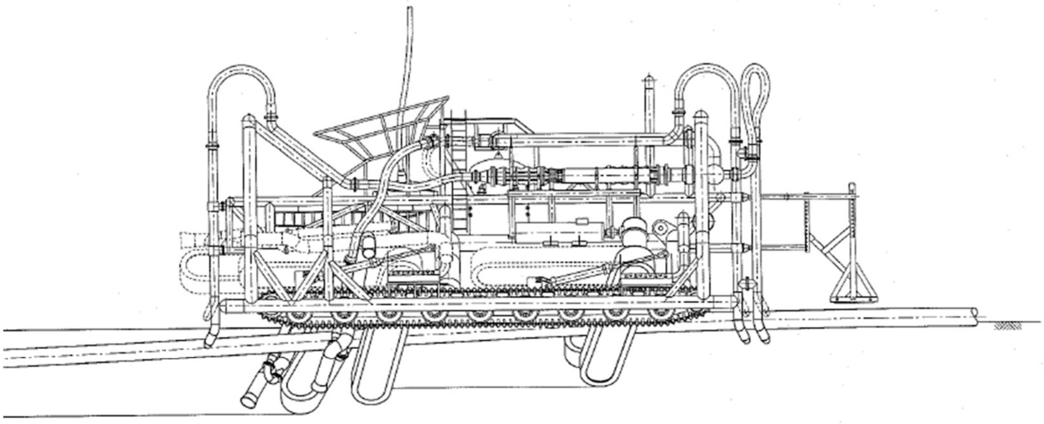
1.0 INTRODUCTION

One-Dyas plans to develop a successfully drilled well in block N5A of the North Sea Dutch Continental Shelf. More wells will be drilled at this location through the same template. It is planned to develop the wells by installing a platform and a gas export pipeline with a connection to the NGT pipeline. Various alternatives for the export pipeline route have been evaluated and a preferred route has been selected for further development; Pipeline route from the future N5A platform location to a subsea hot-tap tie-in at the NGT pipeline near KP 142.1.
In addition, a power cable may be installed from the Riffgat Windpark to the N05A platform.

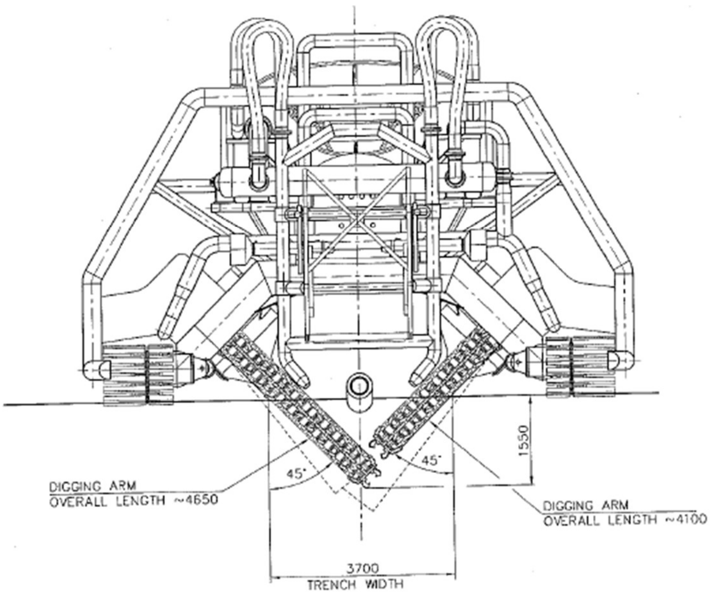
This document describes the different profiles of available pipeline trenching techniques.

2.0 Mechanical Trenching

An example of a mechanical trencher is the Allseas owned Digging Donald. It produces a trench profile slightly wider than its digging arms, depending on soil conditions. Spoil heaps next to the trench are minimal. Drawings of the Digging Donald and typical trench profile are given below.

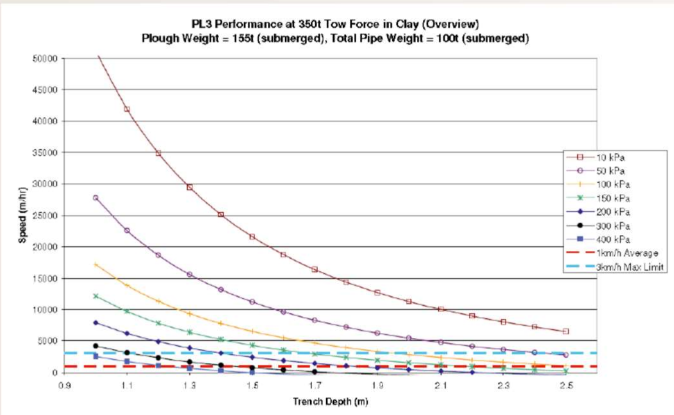


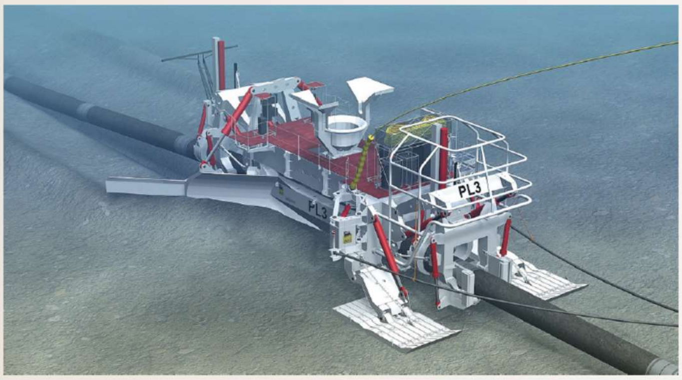
SIDE VIEW "DIGGING DONALD"



3.0 PIPELINE PLOUGH

A pipeline plough is towed behind a trenching support vessel and produces a typically wider profile than a mechanical trencher with slopes of 35 degrees approximately. Next to the trench considerable spoil heaps will be present directly after trenching, with an approximate slope of 20 degrees. An example is given below.





Water Depth:	0-500m. Option to upgrade to 1000m
Trench Depth:	1.5m maximum single pass 2.5m maximum multi-pass
Weight:	Nominal 175t in air, 150t submerged
Dimensions:	22.0m (L) x 12.0m (W) x 10.0m (H)
Design Life:	10 years
Fatigue Life:	1000 days
Pipe Size:	75-1550m maximum overall product diameter
Pipe Support Capacity: Max. vertical support load 100t each end	
Trench Profile:	V-trench with 35° slope angle. Spoil heaps20° depending on soil type.

4.0 JETTING

The jetting method involves using a high-pressure water and air or water educator jet sled. The jet sled is placed over a previously laid pipeline. The jetting process cuts the seabed with high volume pressurized water "jetted out" through typically 100 or more nozzles at the leading edge of the sled and across the bottom of the trench while soil is extracted from beneath the sled via the educator system, which then disperses the fine particles into the water column. While jetting, gravity lowers the pipeline to the bottom of the jetted trench behind the sled. Jetting sleds are generally buoyant and work well in areas where the seabed is composed of the softest fine gained "fluidized" silts as well as in the stiffest clays. Jetting success is directly proportional to the output volume and pressure of the water and air relative to the type of seabed. The higher the water and/or air pressures and/or volumes, the better the jetting performance in most cases.

5.0 TRENCH PROFILE OVERVIEW

An overview of different trenching methods and associated profiles is given below.

Technique	Trench depth [m]	Trench width [m]	Volume of soil replaced [m3/m]	Spoil heaps
Mechanical trenching	1.5	4.0	3.0	Minimal
Ploughing	1.5	4.5	3.4	Large spoil heaps
Jetting	1.5	3.0	2.3	Negligible

6.0 FINDINGS

Jetting seems to be the most favorable method for pipeline burial based on the amount of material removed from the trench compared to a plough and mechanical trenching. A disadvantage of jetting is dispersion of the fine particles in the water column. With a mechanical trencher and plough more soil is moved but less is brought in dispersion compared to the jetting method.

N05a Development

Title	**Habitat Assessment Survey Report - Addendum**
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REVISION HISTORY

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The table on this page can be used to explain the reason for the revision and what has changed since the previous revision.

Rev.	Reason for revision	Changes from previous version
1.0	First Issue	N/A

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

ABBREVIATIONS

The abbreviations listed in Table 1 are used within this report. Where abbreviations used in this document are not included in Table 1, it may be assumed that they are either equipment brand names or company names.

Table 1 Abbreviations used in this document

	Description		Description
2DHR	2-Dimensional High Resolution	OSPAR	Oslo/Paris Convention (for the Protection of the Marine Environment of the North-East Atlantic)
BSL	Benthic Solutions Limited	OWF	Offshore Windfarm
CNS	Central North Sea	PC	Physico-chemical grab sample
CPT	Cone Penetrometer Test	PPP	Precise Point Positioning
EBS	Environmental Baseline Survey	PPS	Pulse per second
ED50	European Datum 1950	ROV	Remotely Operated Vehicle
F1/F2/F3	Fauna grab samples 1, 2 and 3	SBP	Sub-Bottom Profiler
GNSS	Global Navigation Satellite System	SSS	Side Scan Sonar
HAS	Habitat Assessment Survey	UHR	Ultra-High Resolution
KP	Kilometre Post	UKCS	United Kingdom Continental Shelf
LAT	Lowest Astronomical Tide	USBL	Ultra-short Baseline
LED	Light Emitting Diode	UTC	Universal Time Coordinated
MAG	Magnetometer	UTM	Universal Transverse Mercator
MBES	Multibeam Echosounder	VC	Vibro-core
NGT	Noordgastransport	VORF	Vertical Offshore Reference Frames
MSL	Mean Sea Level	WGS84	World Geodetic System 1984
ONE	Oranje-Nassau Energie		

1 INTRODUCTION

1.1 PROJECT OVERVIEW

GEOxyz was contracted by Oranje Nassau Energie (ONE) to undertake a range of geophysical, geotechnical and environmental surveys in block N5A of the Dutch Sector, comprising a site survey and two route surveys (Figure 1 and Table 2) performed onboard the survey vessel Geo-Ocean III between the 1st and 15th May 2019.

- Site survey (1km x 1km) over the N5A exploration well which will be developed by emplacement of the N5A Platform.
- Cable route survey (9km x 1km) from proposed N5A Platform to Riffgat Offshore Windfarm (OWF) Transformer Station.
- Pipeline route survey (15km x 1km) for proposed gas export pipeline from N5A Platform to with a proposed cable route corridor between the N5A Platform location and the Noordgastransport (NGT) hot tap location.

The geophysical surveys comprised acquisition of multibeam echosounder (MBES), side scan sonar (SSS), magnetometer (MAG) and sub-bottom profiler (SBP) data over the site and routes with Sparker multi-channel seismic data also acquired over the site survey area. An additional 4km x 1km cable route survey and 1km x 1km rig site survey was completed for a potential alternative location of the N5a platform.

The environmental survey work comprised a habitat assessment and environmental baseline survey and was carried out by GeoXYZ Offshore UK Limited, supported by Benthic Solutions Ltd (BSL). The objectives of the environmental survey were as follows:

- Identify UKCS sensitive environmental habitats and species (e.g. Annex I Habitats).
- Acquire baseline data to assess the sediment physico-chemical and biological characteristics within the survey area.

The final part of the pipeline route to the NGT hot tap location was subsequently revised to be able to use an existing tie-in point on the NGT pipeline (NP-001). This revised route extended beyond the original 2018 survey corridor, however, additional geophysical survey data was acquired in 2020 over the NGT pipeline which provided full coverage of SSS data and partial coverage of MBES bathymetry data for this route section.

Table 2: Proposed N5A Platform, N5A to Riffgat Cable Route and N5A to NGT Hot Tap Route Locations

ED50, UTM 31N, CM 3° E					
Proposed Location	KP	Easting (m)	Northing (m)	Latitude	Longitude
N5A Platform	0.000	721 607.00	5 954 650.00	53° 41' 32.347" N	06° 21' 23.281" E
End of Route – Riffgat Windpark Transformer Station Location	8.681	730 081.00	5 954 988.00	53° 41' 30.080" N	06° 29' 05.312" E
Original End of Route – NGT hot tap Location	14.675	718 409.00	5 940 429.00	53° 33' 57.806" N	06°17' 53.314" E
Revised End of Route Location	15.167	717 769.00	5 940 236.00	53° 33' 52.524" N	06°17' 18.043" E

This addendum report provides the results of the environmental habitat assessment over the N5a site survey areas (original and alternative) and associated cable and pipeline route survey corridors, with specific reference made to the revised section of the route from KP 15.0 to KP15.167.

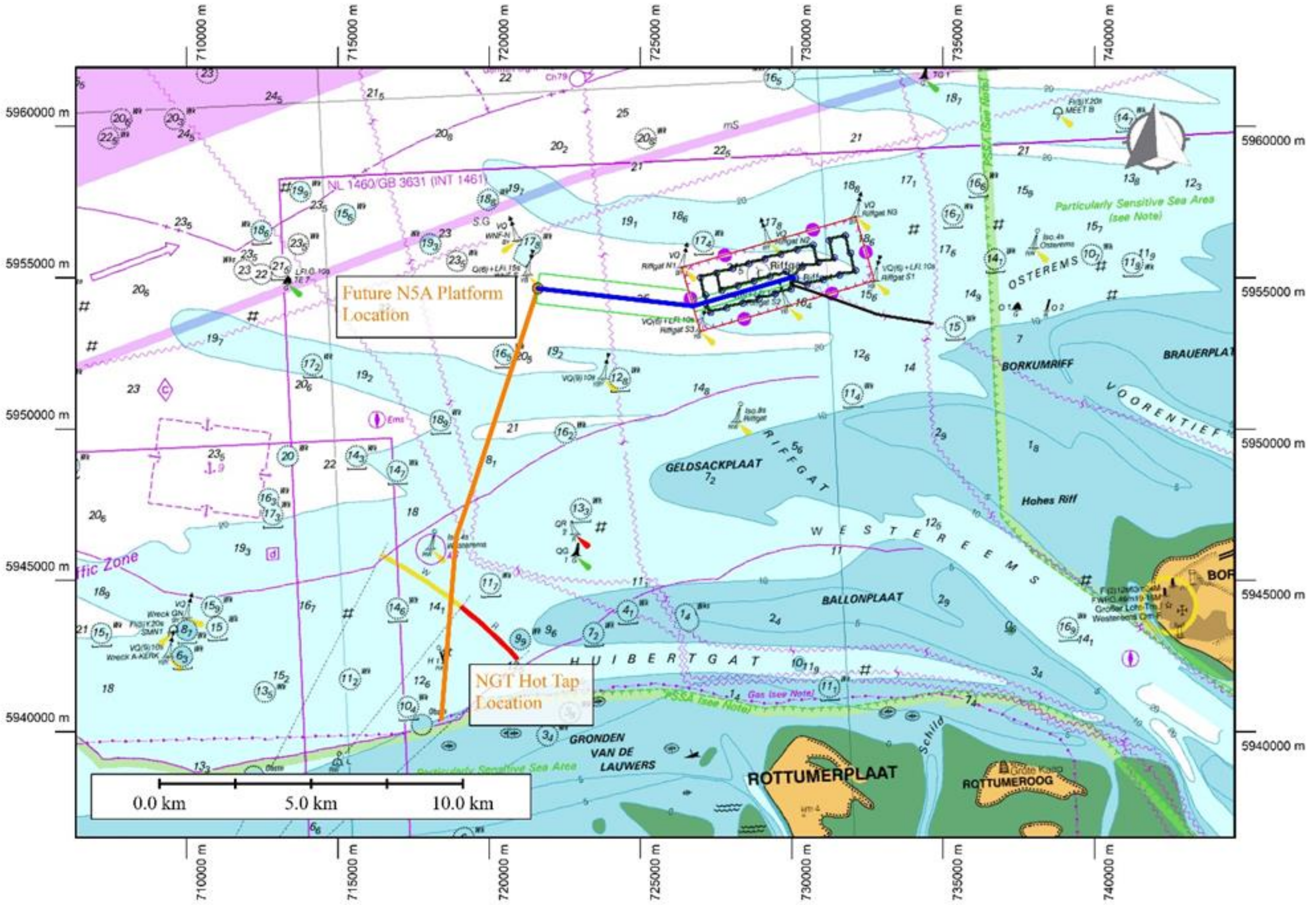


Figure 1: Project location overview

1.2 SCOPE OF WORK

There were three main work areas for geophysical, geotechnical and environmental surveys as described in N5A-7-10-0-70000-01-05 - Pipeline Route and Platform Area Survey Scope. These were:

- Platform Survey Future N5A location;
- Pipeline Route Survey from the future N5A platform location to an existing tie-in point on the NGT pipeline near KP 15.167;
- Cable Route Survey from the future N5A platform location to the Riffgat transformer station.

The following surveys were required by ONE and are described in more detail in Table 3:

- Geophysical Pipeline and Power Cable Route Surveys;
- Geotechnical Pipeline and Power Cable Route Surveys;
- Environmental Pipeline and Power Cable Route surveys including the Platform Area;
- Geophysical Platform Area Survey.

Table 3: Detailed scope of work for each area

Scope	N5A Platform site	Hot Tap Pipeline Route	Riffgat Cable Route
Geophysical Analogue	MBES, SSS, MAG, SBP	MBES, SSS, MAG, SBP	MBES, SSS, MAG, SBP
Geophysical Digital	Multi-channel sparker 80 m depth		
Environmental	Two grab samples within the platform site survey area	Grab sampling each km	Grab sampling each km (including within Riffgat OWF)
Shallow Geotechnical		VC each km	VC each km

The 2018 geophysical survey works were divided between two vessels, with the Geo Ocean III carrying out operations in water deeper than around 10 to 15m LAT and the Geo Surveyor VIII completing operations in the shallower sections. Subsequent geophysical survey over the NGT pipeline, covering the revised section of the pipeline route from KP 15.0 to KP15.167, were acquired by Fugro in 2020.

1.2.1 Objectives

The original 2018 survey objectives were to:

- Accurately determine water depths and seabed topography;
- Provide information on seabed and sub-seabed conditions to ensure the safe emplacement and operation of the proposed pipeline, cable route and platform;
- Assess the area for the presence of any potential sensitive habitats or species, to include EC Habitats Directive (97/62/EC) Annex I habitats and OSPAR threatened and declining habitats and/or species (OSPAR, 2008);
- Acquire environmental baseline samples across the survey area to establish a benchmark against which potential future impacts could be assessed;
- Assess the route corridor for the possible presence of anomalies and boulders/debris that may impede pipelay or cable installation;
- Identify any seabed and sub-seabed features or obstructions.

The objective for the current habitat Assessment addendum report is to extrapolate the previous 2018 habitat assessment across the revised route corridor, making use of available 2018/2020 geophysical datasets, 2018 environmental ground-truthing data and publicly available broad-scale environmental datasets (EMODNet, 2019).

1.3 GEODETIC PARAMETERS

1.3.1 Horizontal Reference

Table 4: Geodetic parameters

Geodetic Parameters	
Spheroid	International 1924
Semi-major axis	6378388.297
Semi-minor axis	6356911.946
Datum	European Datum 1950 (ED50)
Projection	Universal Transverse Mercator (UTM)
False Easting	500000.00
False Northing	0.00
Central Meridian	3° East
Central Scale Factor	0.9996
Latitude of Origin	0°
Grid Zone	31 North
Datum Transformation WGS84 – ED50	
dx	+ 89.5m
dy	+93.8m
dz	+123.1m
Rx	0.0
Ry	0.0
Rz	-0.156
Scale	-1.2ppm

1.3.2 Vertical Reference

All water depths for the original 2018 survey data have been reduced to LAT using the UKHO VORF model. MSL is 1.6m above LAT within the survey area.

The latest 2020 survey data were provided reduced to NAP and not LAT. These data were subsequently offset by +1.95m for approximate consistency with the original 2018 data only.

2 SURVEY DATA REVIEW

2.1 GEOPHYSICAL DATA

Analogue geophysical data acquired by GEOxyz during the survey were used for site selection as no previous geophysical data were available for the survey area. This data was reviewed onboard by BSL and camera transects were selected to target any habitats and boundaries across the survey area, with particular attention paid to the investigation of potential Annex I habitats protected under the EU Habitats Directive. Where features of interest occurred in close proximity to one of the environmental sampling stations, based on the rationale outlined in the scope of work, this station was to be moved slightly to provide additional ground-truthing data for the feature of interest.

The following datasets were available for review during the preparation of this report:

- Bathymetry, reduced and processed offshore to provide a digital terrain model where major bathymetric features and minor bathymetric changes could be identified and highlighted. This included the identification of large features (e.g. linear ridges of cobbles and boulders) and seabed infrastructure (e.g. existing pipelines).
- Side scan sonar (SSS) with data run at both high (400kHz) and low (100kHz) frequencies at ranges varying from 75m to 125m with digital rendering onto a seabed mosaic of the area (100KHz) for review. Changes in sediment type and hardness, along with features observed through low level relief and discrete objects could also be delineated.

2.2 ENVIRONMENTAL GROUND-TRUTHING AND SAMPLING

The environmental sampling strategy was defined by the client prior to the commencement of the survey. Sampling locations along the pipeline and cable routes were positioned every kilometre from the proposed N5a well locations to the shore and to the Riffgat offshore wind farm (Figure 2). Two stations (Grab_P_0 and Grab_P_7) along the pipeline route were repositioned to cover areas of interest identified from the sidescan sonar record (Table 5). At each of these sampling locations a drop-down video assessment was conducted before grab sampling, with video footage acquired at all stations apart from Grab_P_14 where the visibility severely reduced. Additional camera transects were conducted over the proposed N5a well locations and additional areas of interest identified following review of the sidescan sonar record (Table 6).

Seabed video footage was acquired along eight camera transects using a Seabug camera system mounted within a BSL camera sled frame equipped with a separate strobe, and LED lamps. The camera unit itself is capable of acquiring images at 14.7MP resolution but was set to a resolution of 5MP (2592 x 1944 pixels) to optimise image upload times during camera operation.

A BSL Double grab (double Van Veen) was used for seabed sampling, requiring two successful deployments at each location. A maximum of three ‘no sample’ deployments was allowed at each station before abandoning. A 0.1m^2 Day Grab was used on the first deployment, before switching to the BSL Double grab for all remaining deployments at the client’s request.

Table 5: Summary of drop-down camera and grab sampling locations for survey area

ED50, UTM 31N, CM 3° E								
Station	Rationale	Type	Easting (m)	Northing (m)	PC	F1	F2	F3
Grab_P_0	Pipeline Route - Positioned at 1km intervals	EBS/HAS	721619	5954453	Y	Y	Y	Y
Grab_P_1	Moved from KP in order to investigate area of high reflectivity sediment	EBS/HAS	721325	5953791	Y	Y	Y	Y
Grab_P_2	Pipeline Route - Positioned at 1km intervals	EBS/HAS	720981	5952752	Y	Y	Y	Y
Grab_P_3	Pipeline Route - Positioned at 1km intervals	EBS/HAS	720669	5951801	Y	Y	Y	Y
Grab_P_4	Pipeline Route - Positioned at 1km intervals	EBS/HAS	720355	5950850	Y	Y	Y	Y
Grab_P_5	Pipeline Route - Positioned at 1km intervals	EBS/HAS	720041	5949900	Y	Y	Y	Y
Grab_P_6	Pipeline Route - Positioned at 1km intervals	EBS/HAS	719729	5948950	Y	Y	Y	Y
Grab_P_7	Moved from KP to investigate mixed reflectivity sediment	EBS/HAS	719347	5948023	Y	Y	Y	Y
Grab_P_8	Pipeline Route - Positioned at 1km intervals	EBS/HAS	719105	5947052	Y	Y	Y	Y
Grab_P_9	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718861	5945912	Y	Y	Y	Y
Grab_P_10	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718779	5944917	Y	Y	Y	Y
Grab_P_11	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718695	5943920	Y	Y	Y	Y
Grab_P_12	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718614	5942923	Y	Y	Y	Y
Grab_P_13	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718532	5941927	Y	Y	Y	Y
Grab_P_14	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718450	5940930	Y	Y	Y	Y
Grab_P_15	Pipeline Route - Positioned at 1km intervals	EBS/HAS	718366	5939933	Y	Y	Y	Y
Grab_C_0	Original Cable Route and N5a well centre location	EBS/HAS	721610	5954652	Y	Y	Y	Y
Grab_C_1	Original Cable Route – Positioned at 1km intervals	EBS/HAS	722604	5954538	Y	Y	Y	Y
Grab_C_2	Original Cable Route – Positioned at 1km intervals	EBS/HAS	723596	5954425	Y	Y	Y	Y
Grab_C_3	Original Cable Route – Positioned at 1km intervals	EBS/HAS	724588	5954315	Y	Y	Y	Y
Grab_C_4	Original Cable Route – Positioned at 1km intervals	EBS/HAS	725579	5954203	Y	Y	Y	Y
Grab_C_5	Original Cable Route – Positioned at 1km intervals	EBS/HAS	726575	5954089	Y	Y	Y	Y
Grab_C_6	Original Cable Route – Positioned at 1km intervals	EBS/HAS	727355	5954245	Y	Y	Y	Y
Grab_C_7	Original Cable Route – Positioned at 1km intervals	EBS/HAS	728149	5954477	Y	Y	Y	Y
Grab_C_8	Original Cable Route – Positioned at 1km intervals	EBS/HAS	729107	5954756	Y	Y	Y	Y
Grab_C3_0	Secondary Cable Route and N5a second potential well centre location	EBS/HAS	722288	5953018	Y	Y	Y	Y
Grab_C3_1	Secondary Cable Route – Positioned to investigate mixed reflectivity sediment	EBS/HAS	723809	5953378	Y	Y	Y	Y
Grab_C3_2	Secondary Cable Route – Positioned to investigate high reflectivity sediment	EBS/HAS	725337	5953741	Y	Y	Y	Y

Table 6: Summary of camera transect locations for the survey area

ED50, UTM 31N, CM 3° E								
Transect	Rationale	SOL/ EOL	Date and time	Depth (m)	Easting (m)	Northing (m)	No. Stills	Video footage (mm:ss)
Grab P_0	Investigating area of mixed reflectivity sediment	SOL	02/05/2019 17:15:11	30	721647	595443	27	07:13
		EOL	02/05/2019 17:22:21	31	721591	595447		
North Transect 1	Investigating transition from mixed to high reflectivity sediment	SOL	11/05/2019 00:49:10	29	721486	595468	30	10:11
		EOL	11/05/2019 00:59:10	29	721363	595463		
North Transect 2	Investigating transition from low to mixed reflectivity sediment	SOL	11/05/2019 00:06:17	30	721609	595499	41	12:49
		EOL	11/05/2019 00:18:59	28	721631	595515		
North Transect 3	Investigating transition from mixed to high reflectivity sediment	SOL	11/05.2019 02:04:48	29	721902	595440	50	12:29
		EOL	11/05/2019 02:17:13	29	721802	595455		
N5a Transect 1	Transect across original N5a well location	SOL	11/05/2019 01:38:05	29	721585	595458	35	08:37
		EOL	11/05/2019 01:46:38	29	721626	595470		
N5a Transect 2	Transect across original N5a well location	SOL	11/05/2019 01:16:28	28	721668	595463	39	09:13
		EOL	11/05/2019 01:25:35	29	721544	595466		
Grab_C3_0	Transect across second proposed N5a well location	SOL	14/05/2019 21:51:02	24	722231	595298	36	09:15
		EOL	14/05/2019 22:00:14	25	722335	595304		
Grab_C3_2	Investigating area of high reflectivity sediment	SOL	14/05/2019 20:46:00	25	725366	595361	37	12:36
		EOL	14/05/2019 20:58:53	25	725326	595378		

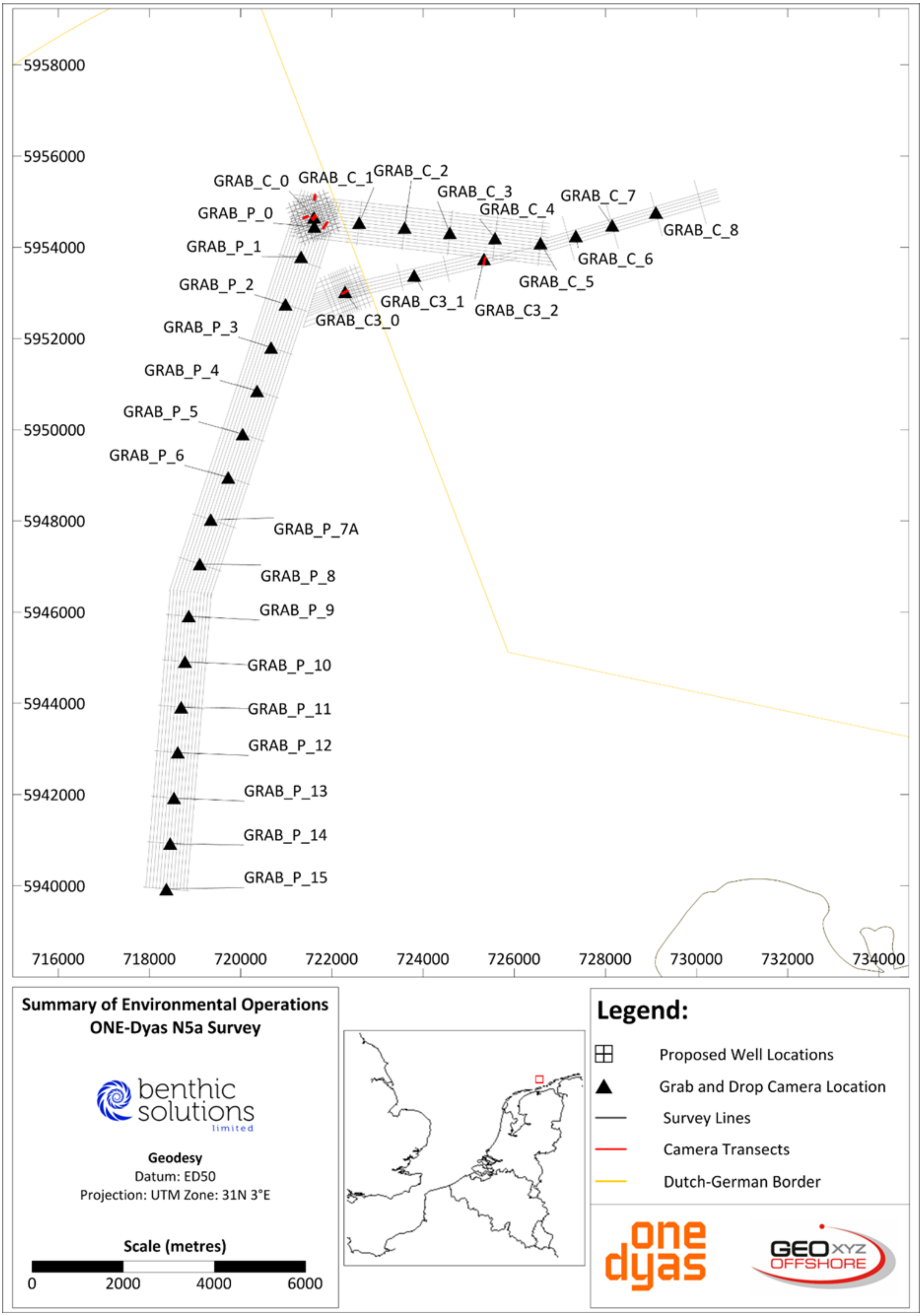


Figure 2: Survey strategy overview

2.3 HABITAT INVESTIGATION

2.3.1 Habitat Classification

A marine biotope classification system for British waters was developed by Connor *et al.* (2004) from data acquired during the JNCC Marine Nature Conservation Review (MNCR) and subsequently revised by Parry *et al.* (2015) to provide improved classification of deep-sea habitats. The resultant combined JNCC (2015) classification system forms the basis of the European Nature Information Service Habitat Classification (EUNIS, 2013), albeit with differing habitat coding nomenclature, which has compiled habitat information from across Europe into a single database. The two classification systems are both based around the same hierarchical analysis. Initially abiotic habitats are defined at four levels. Biological communities are then linked to these (at two lower levels) to produce a biotope classification. (Connor *et al*., 2004; EUNIS, 2013).

Habitat descriptions have been interpreted from the side scan sonar and bathymetric data acquired during the current survey, in conjunction with additional information on seabed sediment types and faunal communities from seabed photography and grab sampling. Global Mapper V21 GIS software was used to review side scan sonar mosaic (Geotiff) and multibeam bathymetry data (Geotiff and xyz) and to delineate areas of different seabed habitats.

To further aid interpretation, comparisons have been made with the predicted broadscale bathymetry (1/16 arc minutes resolution) and seabed habitat distribution data produced by the European Marine Observation and Data Network (EMODnet). EMODnet is a long-term marine data initiative developed through a step-wise approach to collect data and build on existing databases to provide access to European marine data across seven discipline based themes: bathymetry, geology, seabed habitats, chemistry, biology, physics, and human activities (EMODnet, 2019). The broad-scale seabed habitat map is a predictive delineation of habitats within all European seas to the EUNIS classification system (EMODnet, 2019). Formulated through international (OSPAR) and national monitoring programmes in collaboration with European projects, such as MESH or Mesh Atlantic, the predicted seabed habitat map is a useful resource to provide further confidence in the assignment of biotopes within the survey area, including for any areas where there is incomplete coverage of 2018 and 2020 geophysical survey data (multibeam echo sounder bathymetry and side scan sonar).

2.3.2 Assessment of Sensitive Habitats

The Netherlands is a signatory of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention, 1979). To meet their obligations under the convention, the European Community Habitats Directive was adopted in 1992. The provisions of the Directive require Member States to introduce a range of measures including the protection of species listed in the Annexes; to undertake surveillance of habitats and species and produce a report every six years on the implementation of the Directive. The 189 habitats listed in Annex I of the Directive and the 788 species listed in Annex II, are to be protected by means of a network of sites. Each Member State is required to prepare and propose a national list of sites, which will be evaluated in order to form a European network of Sites of Community Importance (SCIs). These will eventually be designated by Member States as Special Areas of Conservation (SACs), and along with Special Protection Areas (SPAs) classified under the EC Birds Directive (2009), form a network of protected areas known as Natura 2000. The Directive was amended in 1997 by a technical adaptation Directive and latterly by the Environment Chapter of the Treaty of Accession 2003.

Based on the above, the OSPAR list of threatened and/or declining species and habitats and Annex I habitats of particular relevance to this region of UK waters are:

- Biogenic reefs formed by *Sabellaria spinulosa* (the Ross Worm); and,
- Sandbanks which are slightly covered by sea water all the time

Stony reefs are an Annex I habitat and are protected under the EU habitats directive. Sampling location Grab_C3_2 showed a high proportion of cobbles and boulders, and consequently a stony reef assessment was conducted. The seabed camera ground-truthing data were assessed for potential stony reefs using the criteria proposed by Irving (2009). While the Irving (2009) criteria have been approved by the UK regulators, they have not been explicitly approved by the Netherlands authorities but are used here to provide semi-quantitative assessment of potential Annex I stony reef habitat. The Irving (2009) method breaks down the assessment criteria into measures of reef 'quality' or 'reefiness', based on a minimum cobble size of 64mm being present and indicating relief above the natural seabed where >10% of the matrix are cobble related and a minimum surface area of around 25m^2 is recorded (see Report LU-0022H-553-RR-04 for further detail).

3 RESULTS AND INTERPRETATION

3.1 BATHYMETRY

The following text was adapted from the 2018 survey reports for the N5A site (LU-0022H-553-RR-01), N5A to NGT Hot Tap pipeline route (LU-0022H-553-RR-02) and N5A to Riffgat cable route (LU-0022H-553-RR-07) to provide an overview of the bathymetry across the survey site and route corridors, augmented by review of 2020 bathymetry data over the revised KP15.0 to KP15.167 section of the pipeline route.

The 2018 bathymetry data were acquired using an R2 Sonics 2022 multi-beam echo sounder for the site and an R2Sonic 2024 multi-beam echo sounder for the two route surveys. All 2018 bathymetry data have been reduced to LAT, which was 1.6m below MSL within the survey area and are presented at a 0.5m x 0.5m bin size. The multibeam echo sounder system used to acquire the 2020 bathymetry data is not known. The 2020 bathymetry data were provided reduced to NAP and offset by +1.95m for approximate consistency with the 2018 LAT data.

To further aid interpretation and put the available survey data in a regional context, comparisons have been made with the predicted broadscale bathymetry (1/16 arc minutes resolution) produced by the European Marine Observation and Data Network (EMODnet, 2019). This data also provides further confidence in assessment of any areas with incomplete coverage of 2018 and 2020 MBES survey data (Figure 3).

3.1.1 N5A to NGT Pipeline (NP-001) Tie-in Route

Water depths along the proposed N5A to NGT Hot Tap pipeline route ranged between 26.4m LAT at KP0.000 and 8.5m LAT at KP15.167 atop a rock dump protecting the existing tie-in point on the NGT pipeline, with the seabed shoaling gently towards the southern end of the proposed pipeline route. A series of natural troughs trending west-north-west to east-south-east occurred within the survey corridor, crossing the proposed pipeline route, the largest of which was approximately 250m wide.

While there was a small triangular area of the proposed N5A to NGT Pipeline (NP-001) Tie-in Route survey corridor which was not covered by the available 2018 and 2020 MBES bathymetry data, this area was covered by the corresponding side scan sonar data, which showed no evidence of bathymetric features of interest in this area (Figure 3). In addition, broad-scale bathymetry data for region showed no evidence of bathymetric features that might contradict the aforementioned interpretation.

A variety of anthropogenic debris/wreck and areas of disturbed seabed were evident on the bathymetry data:

- Two prominent features interpreted as shipwrecks surrounded by seabed scouring; the largest (40.1m x 12.8m x 1.1m) occurred at approximately KP2.462, 369m west-north-west of the proposed route and the other (19.1m x 12.9m x 0.2m) occurred at approximately KP2.373, 339m west-north-west of the proposed route.
- Three semi-circular features with 1m of positive relief, interpreted as being related to previous drilling activity, were observed on bathymetry data. These were observed at the start of the proposed route between KP0.009 and KP0.089, offset by 90m to the east-south-east at their closest approach. These features lay within a 30m radius of each other and exhibited average dimensions of 30m x 30m.
- Three existing cables and one pipeline were expected to cross the proposed pipeline route but were not observed on the bathymetry data.

- An area of rock dump was present at the revised southern end of the pipeline route, overlying the existing tie-in point on the NGP (NP-001) pipeline at KP15.167 (Figure 3). The rock dump extended in excess of 170m from north-west to south-east, was 42m across at its widest point and was elevated between 1.4m and 2.4m above the surrounding seabed.

3.1.2 N5A to Riffgat Cable Route

The seabed shoaled gently towards the east-north-east end of the proposed N5A to Riffgat cable route with water depths ranging between 26.0m at KP0.280 and 19.6m KP7.941. A series of natural troughs, predominantly trending north-west to south-east, crossed the proposed cable route from approximately KP5.158 to KP8.681 and were interpreted to be related to tidal/current processes.

Three semi-circular features with 1m of positive relief, interpreted as being related to previous drilling activity, were imaged in the bathymetry data. These were positioned at the start of the proposed route between KP0.085 and KP0.168; at their minimum offset from the route they were approximately 27m south-south-west. They were positioned within a 30m radius and had average dimensions of 30m x 30m.

The Norned cable was observed crossing the proposed cable route at KP 2.313 trending north-north-west to south-south-east.

3.2 SEABED FEATURES

The following text was adapted from the 2018 survey reports for the N5A site (LU-0022H-553-RR-01), N5A to NGT Hot Tap pipeline route (LU-0022H-553-RR-02) and N5A to Riffgat cable route (LU-0022H-553-RR-07) to provide an overview of the seabed features across the survey area, focussing on features of particular relevance to the environmental baseline and habitat assessment of the survey area. The seabed features interpretation was further augmented by review of 2020 side scan sonar data over the revised KP15.0 to KP15.167 section of the pipeline route (Figure 4).

The 2018 side scan sonar data were acquired with an Edgetech 4200 system operating at 100kHz/400kHz with between 75m and 200m per channel range. This was supplemented by swathe bathymetry data gridded to 0.5m bin size. The side scan sonar system, operating frequency and range used to acquire the 2020 sonar data is not known.

3.2.1 N5A Site

Seabed sediments across the N5A survey area were expected to comprise ‘fine sand with shell fragments’. An area of ‘coarse sand and shell with a high density of sand mason worms and razor clams’ was evident in the north of the survey area, while an area of ‘coarse sand with pebbles and cobbles’ was present in the south. The uppermost sand unit was merely a veneer and the boundary between the sand and the underlying clay outcrops was arbitrary with the potential for some clay to outcrop in the areas interpreted as sand.

Outcrops of clay were interpreted within the survey area, showing a positive relief of up to 0.5m above background seabed levels. Elsewhere accumulations of coarse sand and gravel were also observed on the bathymetry as having positive relief above the ambient seabed, with some accumulations likely to be caused by the stabilising effect of high densities of sand mason worms and razor clams on the seabed.

Within the survey area there was no existing infrastructure other than the previously drilled N5 Well. Seabed scars up to 1.1m high from the rig whilst over the N5-Ruby wellsite were observed on the bathymetry and side scan sonar data. Numerous magnetometer anomalies were observed within this area, however no wellhead or other evidence of the drilling location could be observed at seabed.

3.2.2 N5A to NGT Pipeline (NP-001) Tie-in Route

Seabed sediments along the proposed pipeline route corridor were expected to comprise ‘fine sand and shell fragments’, with occasional areas of ‘coarse sand and shell fragments’. The side scan sonar record for the 2018 and 2020 survey datasets differed visually, however, this was attributed to potential differences in the acquisition systems, weather conditions during survey and data processing.

The 2018 and 2020 mosaics overlapped for a distance of approximately 1.3km along the NGT (NP-001) pipeline with both mosaics showed the presence of relatively homogeneous acoustic facies, indicating little or no change in the seabed sediments between the original and revised pipeline route corridors.

Bedforms were not imaged in the sonar or bathymetry records. However, photographs taken along the route as part of the environmental survey showed clear seabed rippling over the majority of the survey corridor.

Numerous objects interpreted as boulders and items of debris were observed within the proposed pipeline route corridor. Most of the objects interpreted as boulders occurred towards the north of the survey corridor area and coincided with areas of clay exposure.

The most significant objects identified on the sonar records were two interpreted shipwrecks, the largest (40.1m x 12.8m x 1.1m) occurring at approximately KP2.462, 369m west-north-west of the proposed route and the other (19.1m x 12.9m x 0.2m) at approximately KP2.373, 339m west-north-west of the proposed route.

An area of high reflectivity sonar data was present at the revised southern end of the pipeline route, highlighting the presence of a large rock dump overlying the existing tie-in point on the NGP (NP-001) pipeline at KP15.167 (Figure 4). The rock dump extended approximately 170m from north-west to south-east and was 42m across at its widest point.

Three existing cables and one pipeline were expected to cross the proposed pipeline route but were not observed on the bathymetry data.

3.2.3 N5A to Riffgat Cable Route

Seabed sediments along the proposed pipeline route corridor were expected to comprise fine to coarse SAND, with occasional areas of ‘coarse sand and clay with pebbles and cobbles’ and ‘coarse sand with pebbles and cobbles’. Approaching the Riffgate Wind Park, the seabed sediments were dominated by ‘coarse sand and shell fragments’ with occasional patches of ‘coarse sand with pebbles and cobbles’.

Bedforms were not imaged in the sonar or bathymetry records. However, photographs taken along the proposed route corridor as part of the environmental survey clearly showed ripples covering the majority of the seabed within the survey corridor area.

There were numerous objects interpreted as boulders within the proposed pipeline route corridor. Most of the objects, interpreted as boulders occur towards the north of the survey corridor in an area coinciding with areas of clay exposure.

3.3 SHALLOW SOILS

The following text was adapted from the 2018 survey reports for the N5A site (LU-0022H-553-RR-01), N5A to NGT Hot Tap pipeline route (LU-0022H-553-RR-02) and N5A to Riffgat cable route (LU-0022H-553-RR-07) to provide an overview of the shallow soils across the survey area, focussing on the upper layers of relevance to interpretation of the seabed sediment distribution and bathymetric features.

Interpretation of shallow soils across the survey area was based upon pinger and sparker data. Additional information was gained from vibrocore logs and borehole N5-1, 90m south of the proposed Platform Location acquired by Fugro in November 2016. Vibrocore VC_P_0 is at the proposed Platform Location.

3.3.1 N5A Site

The uppermost mappable unit was confirmed as SAND in the vibrocore logs. Where mapped in the western parts of the survey area this unit was under 1.5m thick. This surficial SAND unit was only mappable when thicker than 0.5m and was likely to be present outside the mapped area but at thicknesses below 0.5m.

Three sub units within the Quaternary sequence were interpreted within the area based on the acoustic nature of the sparker data. The uppermost unit, (besides surficial sand mapped from the Pinger data), interpreted within the survey area is a chaotic unit, interpreted to comprise dense to very dense medium to coarse SAND with traces of shell fragments (as sampled within the borehole). Within the survey area, the reflector which correlates with the base of this unit undulates between 1.2m and 18.0m below seabed.

3.3.2 N5A to NGT Pipeline (NP-001) Tie-in Route

This unit of fine to medium grained SAND generally thicken to the south. It was absent (or less than 0.5m thick) from KP 0.430 to KP 0.450 and KP 0.757 to KP 1.045. South of KP 5.951 the base of the mapped unit becomes indistinct to the point of being unmappable, at this point the unit was approximately 9m thick.

The mapped unit was sub-cropped by a sequence of variable composition. Vibrocore logs show that this sub-crop predominantly comprises silty fine SAND except for the area north of KP 1.246 where the subcrop was more clay prone and was interpreted to be the infill of a broad channel.

3.3.3 N5A to Riffgat Cable Route

This unit of fine to medium grained SAND generally thickened to the east. West of the route AC at KP 5.156 the unit was approximately 0.5 to 1m thick or absent/unmappably thin, east of this point the unit locally exceeds a thickness of 2m.

Vibrocore logs showed that the mapped unit was sub-cropped by clay prone deposits from KP0 to KP 3.357, interpreted to be the infill of a broad channel. From KP 3.357 to the end of the route the mapped unit was subcropped by fine SAND.

3.3.4 N5A Site

The seabed within the N5A site survey area sloped gently to the west. The minimum water depth was 23.7m LAT in the NNE of the survey area, while the maximum depth was 26.6m LAT in the WSW. Small areas with relief of up to 0.4m were observed on the bathymetry data with measured gradients of up 6° on their flanks, which were interpreted to be largely due to outcropping clays.

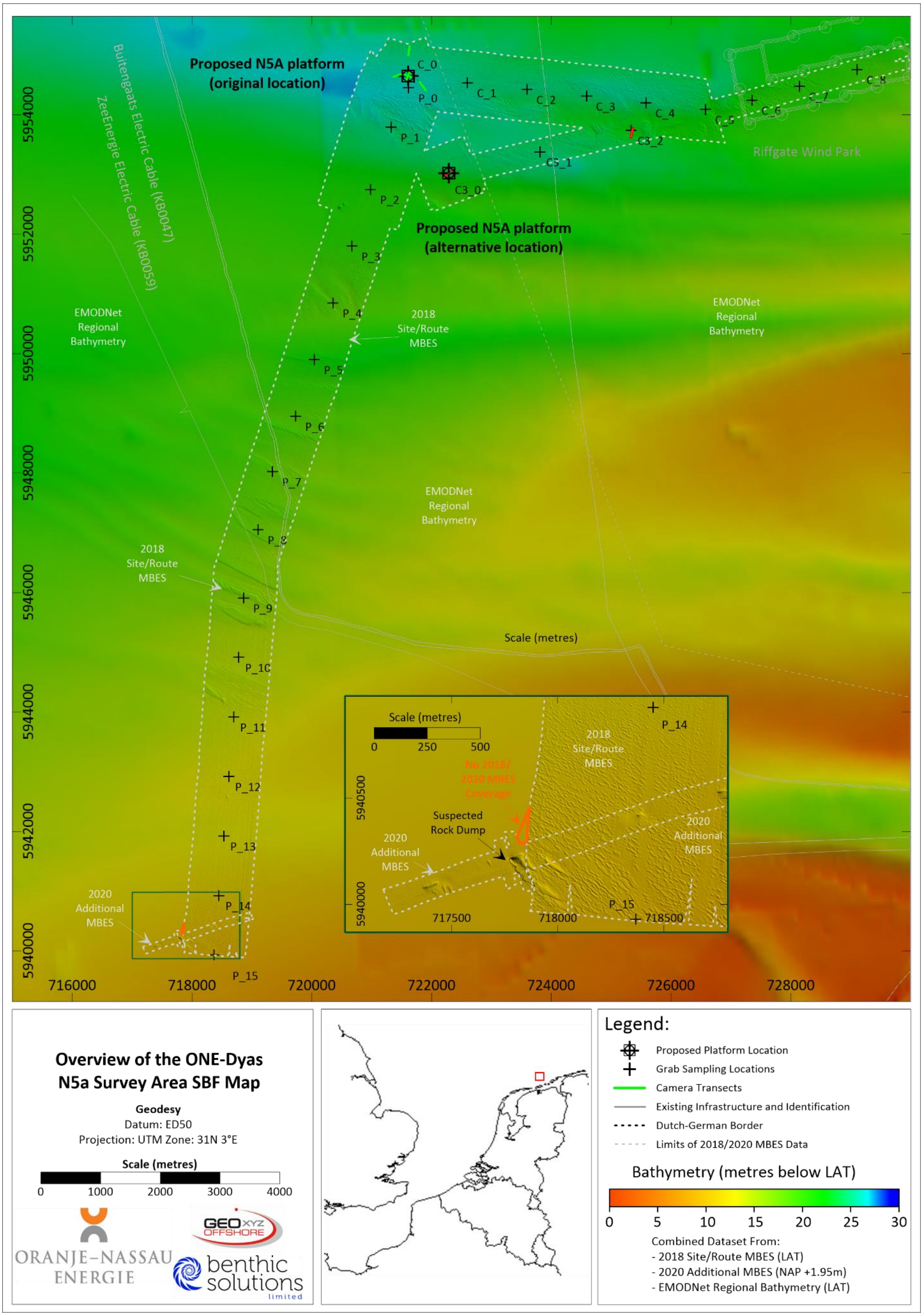


Figure 3: N5A Site and Route Survey Bathymetry

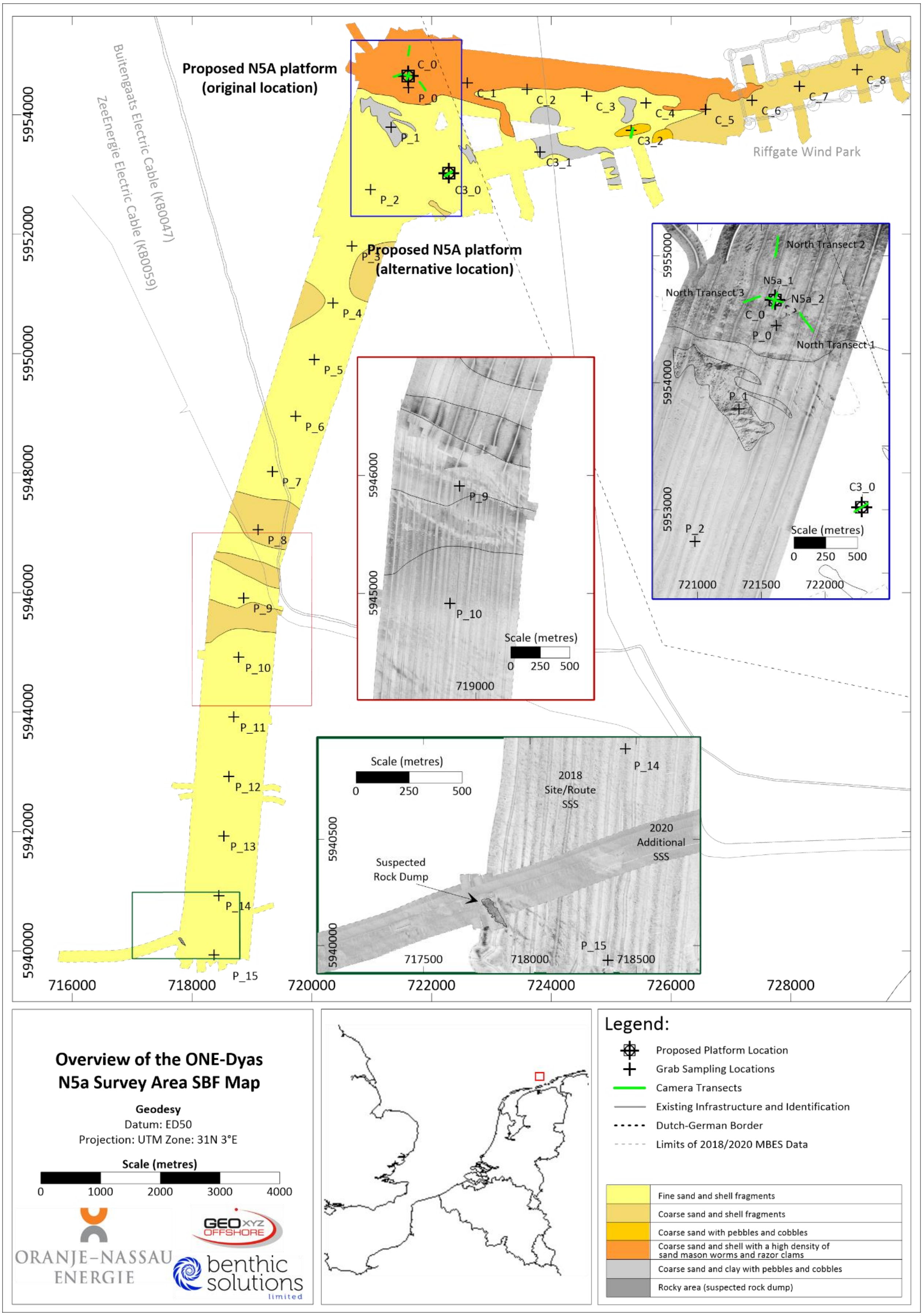


Figure 4: Interpreted N5A Site and Route Seabed Features

3.4 HABITAT ASSESSMENT

3.4.1 Video/Photographic Survey

A total of twenty-eight drop-down camera deployments and eight camera transects were conducted within the combined N5A development site and route survey area. The camera ground-truthing was undertaken to investigate the distribution of different seabed habitats and associated fauna, while additionally assessing the presence or absence of potential sensitive habitats and species. Drop-down camera deployments were undertaken to provide additional data on the composition of the seabed sediment and associated visible fauna. In contrast, the camera transects were selected to investigate areas of different acoustic facies on the side scan sonar record and/or bathymetric features evident on the MBES data. The ground-truthing stations and transects are listed in Table 5 and Table 6, respectively, and their locations are shown in Figure 2 to Figure 4, with summary photopages included in Appendix D.

Seabed video and photographic data were acquired using a Seabug camera system mounted within a BSL camera sled frame equipped with a separate strobe, and LED lamps. The Seabug is capable of acquiring images at 14.7MP resolution but was set to a resolution of 5MP (2592 x 1944 pixels) to optimise image upload times during camera operation.

Video and camera ground-truthing along all of the transects confirmed the presence of sand-dominated substrate throughout the site and route survey areas. While the dominant sediment type was 'fine sand and shell fragments', several patches of coarser sediment were present across the survey area. The N5A site and route survey corridor to the Riffgate Wind Park showed increasingly coarse sediment, including areas of gravel (>2mm), pebble (>4mm) and cobble (>64mm) in addition to sporadic clay outcrops. The area of coarser substrate along the northern edge of the N5A site and the route survey corridor to the Riffgate Wind Park also supported significant densities of sand mason worms (*Lanice conchilega*) and razor clams (*Ensis* sp., possibly *E. leei*). Although both *L. conchilega* and *E. leei* were observed elsewhere within the N5A site and along the route to the wind park, they were less numerous and more patchily distributed outside the area of the delineated area of 'coarse sand and shell with a high density of sand mason worms and razor clams'. Habitat assessment logs for each of the nineteen camera transects locations are included in Appendix B.

Conspicuous epifauna showed moderate diversity and density for a predominantly mobile sandy seabed. Camera ground-truthing stations and transects across all mapped seabed habitats showed a similar species assemblage including frequent observations of sand mason worms (*Lanice conchilega*) and common starfish (*Asterias rubens*). Other species observed more sporadically throughout the combined N5A site and route survey area included razor clams (*Ensis* sp. possibly *E. leei*), burrowing anemones (Cerianthidae), swimming crabs (*Liocarcinus* sp.), masked crabs (*Corystes cassivelaunus*), hermit crabs (Paguridae sp.), edible crabs (*Cancer pagurus*), brittlestars (Ophiuridae), gobies (Gobiidae), dragonets (*Callionymus lyra*), flatfish (Pleuronectiformes) and sandeels (*Ammodytes* sp.).

Areas of coarser substrate, including the delineated area of 'coarse sand and shell with a high density of sand mason worms (*L. conchilega*) and razor clams (suspected *E. leei*)', were characterized by higher abundances of all of the aforementioned fauna with additional observations of plumose anemones (*Metridium senile*), unidentified anemones (Actiniaria), cuttlefish (Sepiidae), European squid (*Loligo vulgaris*), common dab (*Limanda limanda*) and grey gurnard (*Eutriglia gurnardus*).

Example photographs of the common and/or conspicuous faunal groups encountered during the N5A development survey are provided in Appendix D.

3.4.2 General Habitats

Video and still photography ground-truthing from twenty-eight drop-down camera deployments and eight camera transects confirmed the presence of a predominantly sandy seabed with spatial variability in the proportions of shell fragments, coarse substrate (gravel, pebbles and cobbles) and outcropping clay. In addition, an areas of coarse substrate along the northern edge of the survey area supported high densities of sand mason worms (*Lanice conchilega*) and razor clams (suspected *Ensis leei*).

Habitats were identified using a combination of field observations, detailed review of video footage and still images. Based on the ground-truthing data obtained from the N5A development site and route survey area, four EUNIS habitat classifications were assigned: 'Infralittoral fine sand' (A5.23), 'Infralittoral coarse sediment' (A5.13), 'Infralittoral Mixed Sediment' (A5.43) and 'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137). An additional area of suspected rock dump was identified overlying the NGP (NP-001) Pipeline tie-in point. The habitat classifications for the N5A development survey area are illustrated in Figure 9.

The habitat mapping and interpretation made using a combination of the 2018/2020 geophysical survey data and the 2018 environmental ground-truthing data showed good general agreement to the predicted EMODNet (2019) boundaries for the region. As observed from the 2018/2020 data, the region as a whole was predicted to comprise sandy sediments. While the EMODNet (2019) predicted habitat distribution included fewer sandy habitat variants than interpreted from the survey data, there was evidence that predicted minor EMODNet habitat boundaries coincided with those interpreted from the survey data; for example areas of delineated 'Infralittoral coarse sediment' (A5.13) located midway along the pipeline route. Areas of EMODNet (2019) predicted coarse sediment toward the north of the site also showed close agreement with interpreted boundaries of 'Infralittoral Mixed Sediment' (A5.43) and 'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137).

<u>'Infralittoral Fine Sand' (A5.23)</u>

Habitats dominated by fine sand with variable levels of shell debris were dominant across the survey area, being observed on the majority of environmental camera drops and transects within the N5A site and route survey area. These areas were represented by relatively smooth and low reflectivity side scan sonar data and were classified as the 'fine sand and shell fragments' seabed features type (Section 3.2 and Figure 4) and the EUNIS level 4 'Infralittoral fine sand' (A5.23) habitat type (Figure 9).

With the exception of the area of rock dump overlying the NGT (NP-001) pipeline, the revised section of the proposed pipeline route from KP15 to KP15.167 is also interpreted to comprise 'infralittoral fine sand' habitat. The homogeneity of the southern section of the 2018 sonar record and the 2020 sonar record, including a section of circa 1.3km of overlapping data provides high confidence in the consistency of seabed habitat across this area. Furthermore, stations P10 to P15 were all positioned within this uniform area of seabed habitat and each station showed the presence of 'infralittoral fine sand' (See Figure 5 and Appendix D).

'Infralittoral fine sand' habitat is typically characterised by clean sands which occur in shallow water, either on the open coast or in tide-swept channels of marine inlets in water depths of around 0 to 20m. The habitat typically lacks a significant seaweed component and is characterised by robust fauna, particularly amphipods (*Bathyporeia*) and robust polychaetes including *Nephtys cirrosa* and *Lanice conchilega*. Within the N5A development survey area, this habitat comprised clean rippled sands in water depths of approximately 13 to 30m, slightly exceeding the typically expected range.

Visible fauna from camera ground-truthing within areas of 'infralittoral fine sand' included low to moderate densities the sand mason worm (*L. conchilega*) throughout, in addition to several other taxa characteristic of this EUNIS habitat, including common starfish (*Asterias rubens*), swimming crab (*Liocarcinus*) and hermit crabs (Paguridae). Other fauna observed within areas of this habitat included lugworms (*Arenicola* sp.), masked crab (*Corystes cassivellaunus*), edible crab (*Cancer pagurus*), razor clams (*Ensis* sp.), brittlestars (Ophiuridae), gobies (Gobiidae), dragonets (*Callionymus lyra*), flatfish (Pleuronectiform). Further taxa evident from grab samples included occasional sandeel (Ammodytidae), heart urchins (*Echinocardium cordatum*), ragworms (*Nereis* spp.), unidentified sea urchins (spatangoid) and porcelain crab (Portunidae).

Review of the seabed camera and grab sample data indicated that the mapped distribution of 'infralittoral fine sand' (A5.23) habitat was fairly accurate. Only station P_9 showing more coarse sandy sediment than would be expected for 'infralittoral fine sand' habitat but, as this sampling station was located within an area of alternating bands of 'infralittoral fine sand' and 'infralittoral coarse sand', it is to be expected that there will be some discrepancies in this area. Some sporadic patches of higher density *L. conchilega* aggregations were evident on seabed camera data from mapped areas of 'infralittoral fine sand' but these were insufficiently widespread or dense to warrant classification as 'Dense Lanice conchilega and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) habitat.

Example images of 'Infralittoral Fine Sand (A5.23) habitat are given below in Figure 5, the expected extent of the habitat is mapped in Figure 9 and example images for conspicuous fauna and each ground-truthing deployment and are provided in Appendices F and H, respectively.

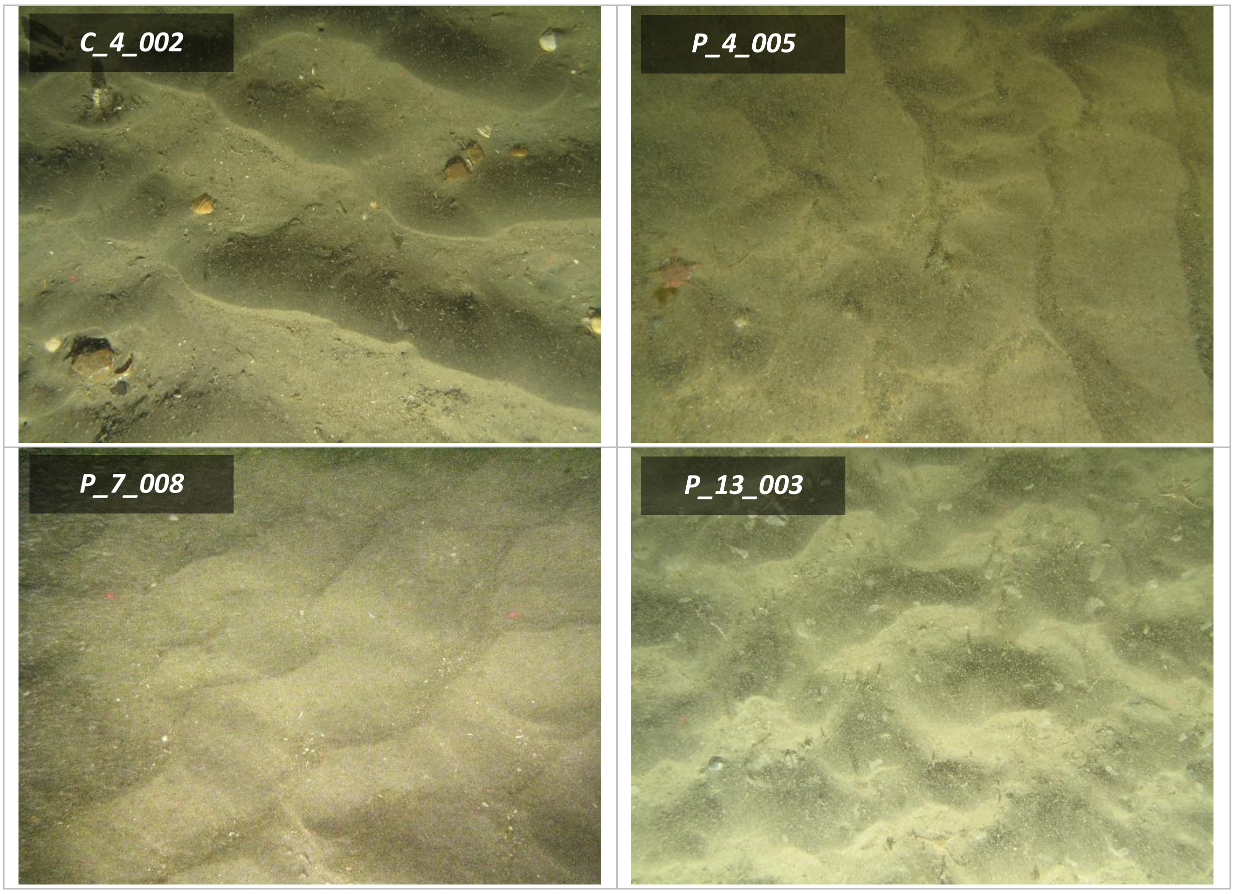


Figure 5: Example images of 'Infralittoral fine sand' (A5.23)

‘Infralittoral Coarse Sediment’ (A5.13)

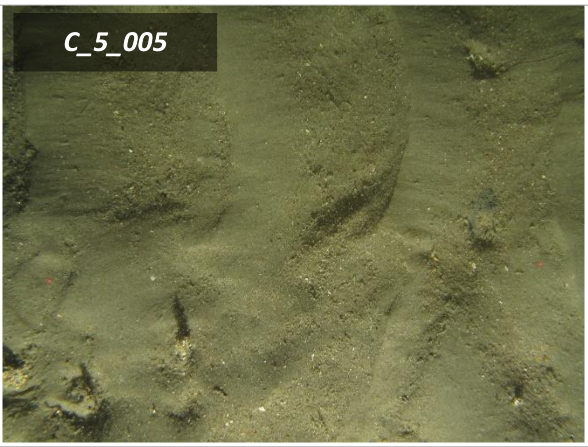
Habitats dominated by coarse sand and moderate levels of shell debris and, occasionally, with gravel and pebbles were found in several patches across the combined N5A development site and route survey area, ground-truthed by stations C_5 to C_7, P_8 and P_9. These areas were represented by relatively smooth but low to moderate reflectivity side scan sonar data and were classified as the ‘coarse sand and shell fragments’ seabed features type (Section 3.2 and Figure 4) and the EUNIS level 4 ’infralittoral coarse sediment’ (A5.13) habitat type (Figure 9). Seven patches of ‘infralittoral coarse sediment’ were mapped, including a large patch on the route survey corridor around the Riffgate Wind Park and a further six smaller patches along the N5A to NGT Hot Tap pipeline route.

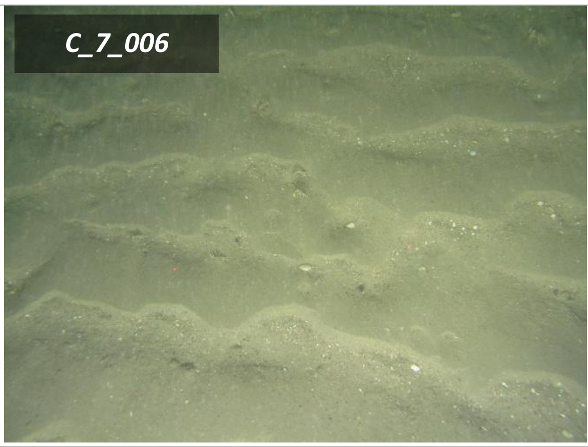
‘Infralittoral coarse sediment’ habitat is typically characterised by coarse sand, gravelly sand, shingle or gravel which are subject to disturbance by tidal streams and wave action in water depths of around 0 to 20m. The habitat is characterised by a robust fauna of infaunal polychaetes such as *Chaetozone setosa* and *Lanice conchilega*, cumacean crustacea such as *Iphinoe trispinosa* and *Diastylis bradyi*, and venerid bivalves. Within the N5A development survey area, this habitat comprised rippled coarse shelly sands, sometimes with a discernible gravel and/or pebble content in water depths of approximately 19 to 30m, slightly exceeding the typically expected range.

Visible fauna from camera ground-truthing within areas of ‘infralittoral fine sand’ included low to moderate densities the sand mason worm (*L. conchilega*) throughout, in addition to common starfish (*Asterias rubens*), which are both characteristic species for this EUNIS habitat. The majority of other characterising taxa for this habitat are infaunal species are not effectively assessed from seabed camera ground-truthing.

Review of the seabed camera and grab sample data indicated that the mapped distribution of ‘infralittoral coarse sediment’ (A5.13) habitat was fairly accurate, but with two exceptions. Station C_0 was classified as ‘infralittoral coarse sediment’ habitat but was located within an area of ‘Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand’ (A5.137) habitat, while station C_8 was classified as ‘infralittoral fine sand’ habitat but was located within an area of ‘infralittoral coarse sediment’. Both of these exceptions reflect the heterogenous nature of the seabed habitats within the survey area.

Example images of ‘infralittoral coarse sediment (A5.13) habitat are given below in Figure 6, the expected extent of the habitat is mapped in Figure 9 and example images for conspicuous fauna and each ground-truthing deployment and are provided in Appendices F and H, respectively.





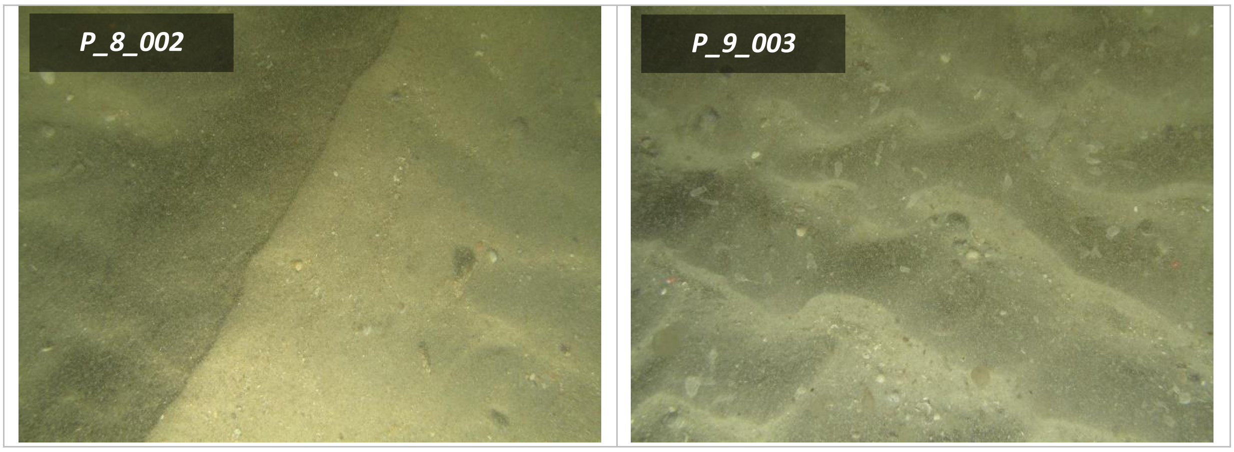


Figure 6: Example images of 'Infralittoral coarse sediment' (A5.13)

'Infralittoral Mixed Sediment' (A5.43)

Habitats dominated by coarse gravelly sand with pebbles, cobbles and, in some areas exposed clay clasts, were found delineated in ten patches across the combined N5A development site and N5A to Riffgate route survey area. These areas were classified as the 'coarse sand with pebbles and cobbles' seabed features type (Section 3.2 and Figure 4) and the EUNIS level 4 'infralittoral mixed sediment' (A5.43) habitat type (Figure 9). Two patches located midway along the N5A to Riffgate cable route showed moderate to high reflectivity side scan sonar signatures but showed no evidence of clay on ground-truthing data from station C3_2. A further ten patches along the N5A to Riffgate route showed similar mottled side scan sonar signatures and may include exposed clay, as evident from ground-truthing at stations P_1 and C3_1 over two of the patches.

'Infralittoral mixed sediment' habitat is typically characterised by mixed muddy gravelly sands or very poorly sorted mosaics of shell, cobbles and pebbles embedded in mud, sand or gravel in water depths of around 0 to 30m. Due to the variable nature of the sediment type, a wide array of communities are reported to be found in areas of mixed sediment, including those characterised by bivalves, polychaetes and file shells. Within the N5A development survey area, this habitat comprised coarse gravelly sand with pebbles, cobbles and sometimes with the addition of exposed clay clasts, in water depths of approximately 24 to 27m, slightly exceeding the typically expected range.

Visible fauna from camera ground-truthing within areas of 'infralittoral fine sand' included common starfish (*Asterias rubens*) and burrowing anemones (Cerianthidae) which are both characteristic species for this EUNIS habitat. Seabed ad grab sample photographs from station C3_1 show numerous holes within the exposed clay clasts which may indicate the presence of boring piddock bivalves (typically *Pholas dactylus* or *Barnea candida*), although no live individuals could be discerned from the seabed or grab sample photographs. While piddocks are not protected by legislation, they are not widespread in the marine environment and would therefore be worthy of note if recorded within the macrofaunal analysis dataset at these stations. In the absence of confirmed piddock presence at these stations, the 'infralittoral mixed sediment' (A5.43) habitat has been assigned, however, this should be amended to 'piddocks with a sparse associated fauna in sublittoral very soft chalk or clay' (A4,231) habitat if piddocks are identified in the grab samples.

Example images of 'infralittoral coarse sediment (A5.13) habitat are given below in Figure 7, the expected extent of the habitat is mapped in Figure 9 and example images for conspicuous fauna and each ground-truthing deployment and are provided in Appendices F and H, respectively.

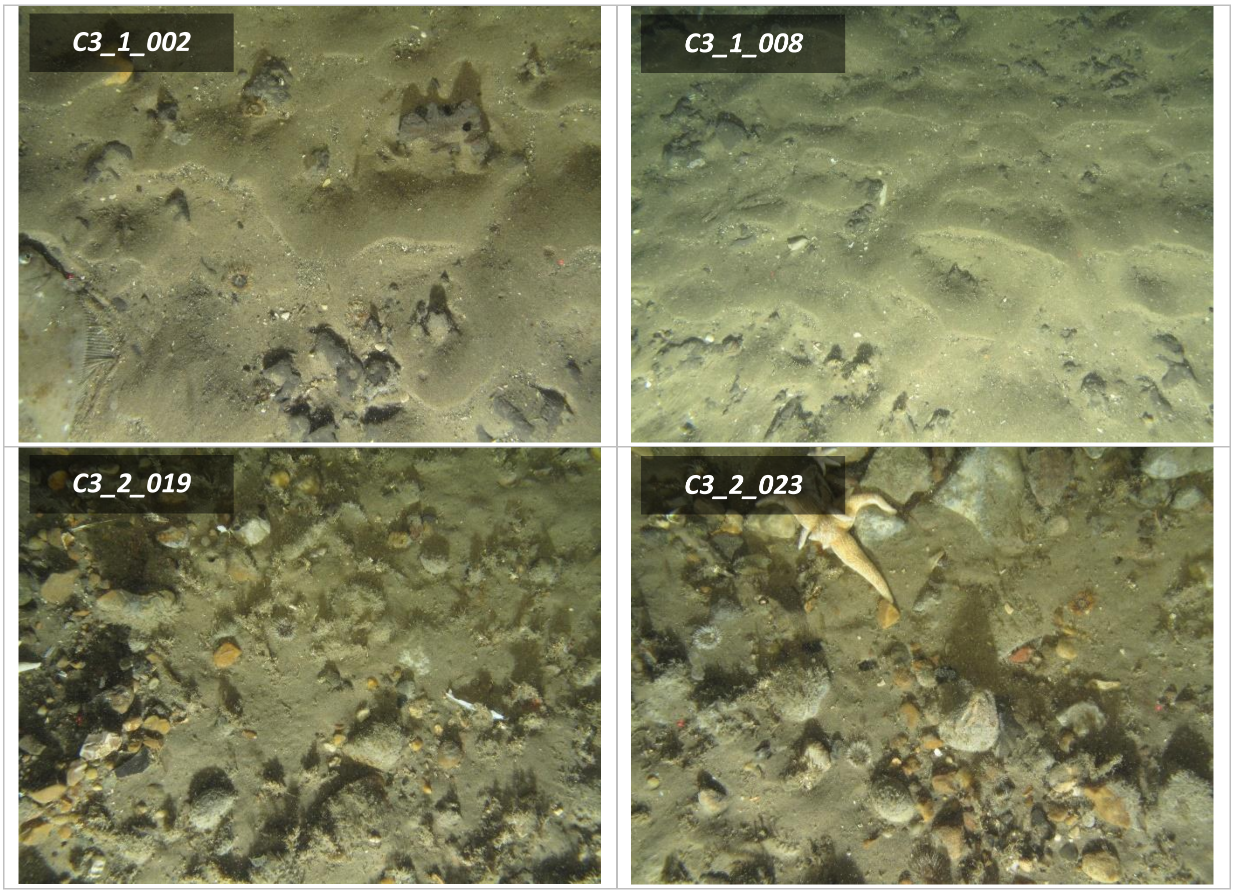


Figure 7: Example images of 'Infralittoral mixed sediment' (A5.43)

'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137)

Habitats dominated by gravelly, shelly coarse sand with moderate to high densities of *Lanice conchilega* were evident at several ground-truthing locations (stations C_1, C_2 and P_0, and transects N5A_1, N5A_2, NT_1, NT_2 and NT_3) within the N5A site and to the east along the N5A to Riffgate Wind Park route. These areas were represented by mottled low to high reflectivity side scan sonar data and were classified as the 'coarse sand and shell with a high density of sand mason worms and razor clams' seabed features type (Section 3.2 and Figure 4) and the EUNIS level 4 'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) habitat type (Figure 9). This habitat was delineated in a single large area along the northern edge of the combined N5A survey area.

'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' habitat is typically characterised by coarse sand, gravelly sand, shingle or gravel which are subject to disturbance by tidal streams and wave action in water depths of around 0 to 20m. The habitat is characterised by high densities of *L. conchilega*, which are thought to stabilise the seabed and allow the development of a more diverse associated faunal community. Within the N5A development survey area, this habitat comprised gravelly, shelly coarse sands in water depths of approximately 28 to 29m, slightly exceeding the typically expected range.

Visible fauna from camera ground-truthing within areas of 'dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' included moderate to high densities the sand mason worm (*L. conchilega*) throughout. Razor clams (*Ensis* sp.) are also associated with this habitat and were seen in very high densities on the majority of ground-truthing data for this habitat. Preliminary review of macrofaunal sample data indicated that the majority of, if not all, the razor clams are the Atlantic jackknife clam (*Ensis leei* – synonyms include *Ensis arcuatus* and *Ensis americanus*). In addition, a number of other characterising taxa for this EUNIS habitat were observed, including common starfish (*Asterias rubens*), lugworms (*Arenicola* sp.), hermit crabs (Paguridae) and swimming crabs (*Liocarcinus*). The majority of other characterising taxa for this habitat are infaunal species are not effectively assessed from seabed camera ground-truthing.

Review of the seabed camera and grab sample data indicated that the mapped distribution of 'dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) habitat was fairly accurate, with the exception of station C_0 which was classified as 'infralittoral coarse sediment' habitat but was located within an area of 'dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) habitat. However, the mapped area of this habitat is expected to be highly heterogenous and will likely include areas of all other mapped habitats from this survey.

Example images of 'dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) habitat are given below in Figure 8, the expected extent of the habitat is mapped in Figure 9 and example images for conspicuous fauna and each ground-truthing deployment and are provided in Appendices F and H, respectively.

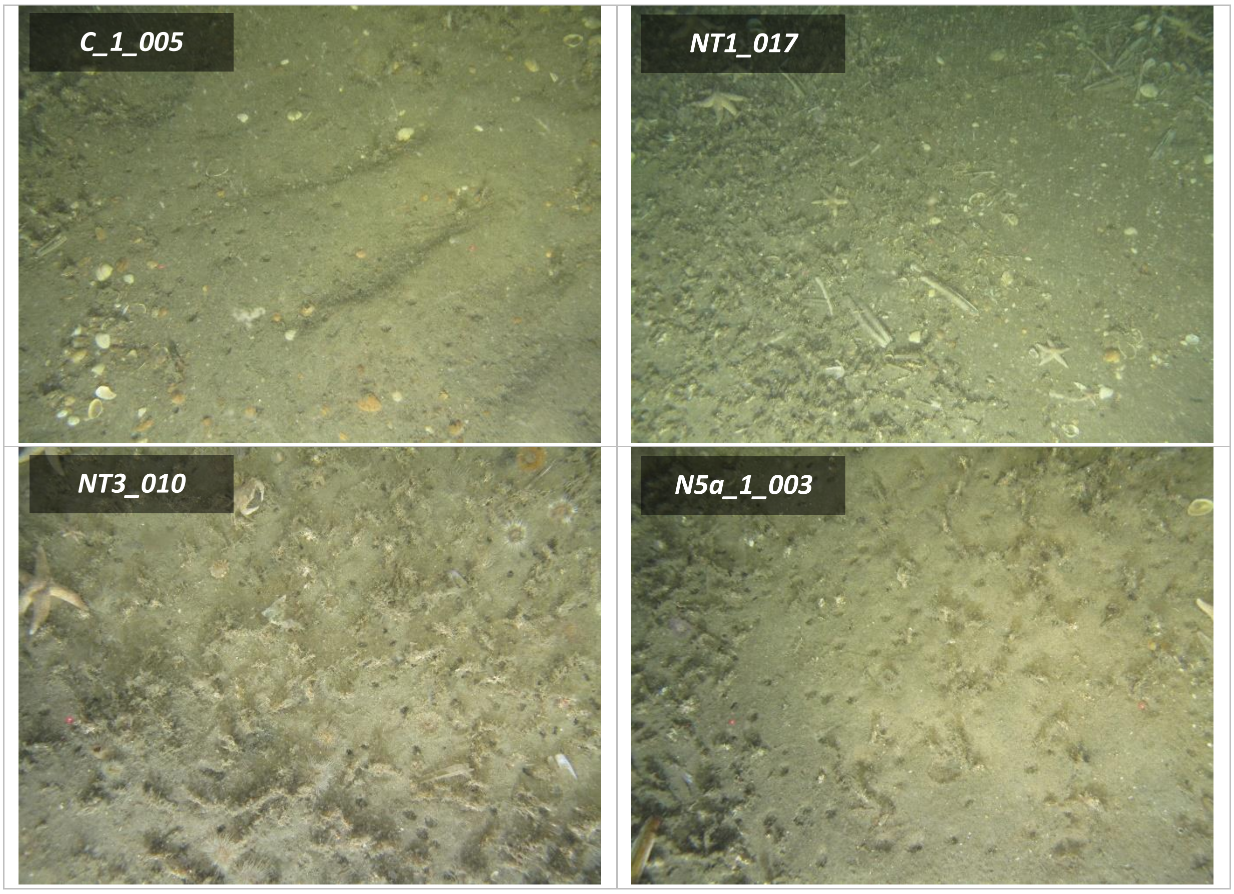


Figure 8: Example images of Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137)

3.4.3 Potential Sensitive Habitats and Species

There are a number of potential sensitive habitats and species which are listed by one or more International Conventions, European Directives or UK Legislation and are known to occur in the wider region (southern North Sea), including:

- Biogenic reefs formed by the ross worm *Sabellaria spinulosa* (EC Habitats Directive Annex I and OSPAR threatened and declining habitat);
- Stony reefs formed by aggregations of cobbles and/or boulders (EC Habitats Directive Annex I);
- 'Sandbanks which are slightly covered by sea water all the time' (EC Habitats Directive Annex I).

Biogenic Reef Habitat

The most likely biogenic reef habitats to occur in sandy habitats in the southern North Sea are biogenic reefs formed by the polychaete worm *Sabellaria spinulosa*, also known as the ross worm. Ross worms build tubes from sand and shell fragments and where large numbers can form reefs. *Sabellaria spinulosa* form reef-like or agglomerations of sand tubes that act to stabilise cobble, pebble and gravel habitats, providing a consolidated habitat for epibenthic species. The aggregations of the tube-building polychaete worm are solid (albeit fragile), and can form large structures at least several centimetres thick, raised above the surrounding seabed, and persist for many years. A such they provide a biogenic habitat that allows many other associated species to become established (Holt et al., 1998 Foster-Smith and White, 2001, Gubbay, 2007).

These reefs are ecologically important as they provide a habitat for a wide range of other seabed dwelling organisms and as such can support a greater biodiversity than the surrounding area. Due to their conservation importance they are listed as an EC Habitats Directive Annex I habitat (Habitats Directive 1992 & 1997) and an OSPAR (2008) threatened and declining habitat. However, no evidence of *S. spinulosa* aggregations was seen on any of the video transect data from the survey area, including transects over areas of high or variable reflectivity coarse or mixed sediments.

While *Lanice conchilega* beds are not listed by either the EC Habitats Directive (EC, 2013) or OSPAR (2008) as protected habitats, Rabaut et al. (2007) highlighted the role of *L. conchilega* as 'ecosystem engineers' which act to stabilise otherwise mobile seabed substrates and facilitate the development of more diverse macrofaunal communities (Rabaut et al, 2007). Furthermore, it has been suggested that *Lanice conchilega* beds meet the qualifying criteria for inclusion as EC Habitats Directive Annex I habitats (Rabaut et al, 2009).

Stony Reef Habitat

Stony reefs are defined by the Habitats Directive as comprising 'areas of boulders (>256mm diameter) or cobbles (64mm – 256mm diameter) which arise from the seafloor and provide suitable substratum for the attachment of algae and/or animal species' (EC, 2013).

The seabed video footage was analysed to assess broad habitat changes across the survey area, and to identify areas any with potential for stony reef habitats (See Appendix B). Only one seabed camera transect (Station C3_2) within the N5A development survey area exhibited any potential for consideration as a potential stony reef (EC, 2013). As such, the video footage from station C3_2 was assessed further using the BSL-modified stony reef assessment method (after Irving, 2009). While the Irving (2009) criteria have been approved by the UK regulators for application in UK waters, they have not been explicitly approved by the Netherlands authorities. However, this method has been used here as a useful basis for semi-quantitative assessment of potential Annex I stony reef habitat.

The results of reef structure analysis are provided in full in the Habitat Assessment Report (Report LU-0022H-553-RR-04), and highlighted the limited potential for the area to be classified as a stony reef due to the low percentage cover and elevation of cobbles (>64mm diameter) in this area. As such, this area is not considered to be sufficiently noteworthy to be classified as an EC Habitats Directive Annex I stony reef.

Shallow Sandbanks Habitat

Sandbanks which are slightly covered by sea water all the time are sandy sediments that are permanently covered by seawater and typically at depths less than 20m (LAT) and are of conservation value as they can host maerl beds as well as being typically colonised by a range of burrowing fauna, epifauna and sand eels, which are an important food source for many birds. Although much of the survey area is shallower than 20m LAT, there were no defined sandbank features in this area (Figure 1).

Due to the variety of H1110 habitat in the Netherlands, the Dutch government decided to subdivide this into three subtypes; H1110_A Wadden Sea, H1110_B North Sea and H1110_C Offshore (Noordzeeloket, 2019). Habitat H1110_C is of most relevance to the current survey area representing permanently flooded sandbanks in water depths of up to 40m, with the Dogger Bank being the main area currently protected under this habitat subtype offshore of the Netherlands. At present, no habitat profile document has been finalised for habitat subtype H1110_C. However, some key characteristics for compiling this profile document are available in Jak et al., (2009), with requirements including the presence of sandy seabed and species characteristic of H1110_C habitat (Table 7).

With the sediments within the survey area being classified within one of three Folk designations of 'sand', 'slightly gravelly sand' and 'gravelly sand', the N5A Development survey sediments can be considered to be sufficiently sandy to meet the requirements of the H1110_C habitat subtype. Review of the macrofauna species dataset together with the grab sample and seabed video logs for the current survey, showed that several of the species characteristic of the H1110_C habitat subtype were present within the survey area. In particular, sandmason worms (*Lanice conchilega*) and bathyporeid amphipods (*Bathyporeia guilliamsoniana*, *B. elegans* and *Bathyporeia* spp.) were recorded in almost all grab samples from the survey area. Other characterising species for the permanently flooded sandbank H1110_C habitat subtype present within the survey area included the polychaete *Sigalion mathildae* and sandeels (*Ammodytes marinus*).

With both the sediment type and associated fauna present within the survey area meeting the requirements outlined by Jak et al., (2009), it is possible that the survey area will be considered to represent EC Habitats Directive Annex I habitat subtype H1110_C (permanently flooded sandbank) throughout N5A Development site and route survey areas. However, there is currently insufficient information in the public domain to pre-empt this decision.

Table 7: Species characteristic of permanently flooded sandbank – Netherlands habitat subtype H1110_C

Species Group	Common Name	Species Name	Description
Polychaete	**Sandmason**	***Lanice conchilega***	**Species occurring on sand substrate**
Polychaete	**na**	***Sigalion mathildae***	**Mainly occurring in clean sandy substrates, Dogger Bank one of the areas where the species occurs.**
Crustacea	**Sand digger shrimp**	***Bathyporeia guilliamsoniana***	**Epiphytes in clean sand and on Dogger Bank**
Crustacea	**Sand digger shrimp**	***Bathyporeia elegans***	**Occurring in coarse, clean, low-fines sediments**
Crustacea	Cumacean	*Iphinoe trispinosa*	Specific for sand from Dogger Bank
Echinodermata	Brittlestar	*Acrocnida brachiata*	Occurring in high densities in clean sand up to a depth of 40 m
Echinodermata	Pea urchin	*Echinocyamus pusillus*	Found in coarse sand and fine gravel enriched with detritus
Mollusca	Ocean quahog	*Arctica islandica*	Occurs on edges of the Dogger Bank - long-lived species

Species Group	Common Name	Species Name	Description
Mollusca	Common whelk	*Buccinum undatum*	Occurs on mixed substrate – long-lived species
Mollusca	Bivalve	*Mactra coralina*	Long-lived species that feeds on particles from the water column. Found in fine to coarse sand
Fish	**Lesser sandeel**	***Ammodytes marinus***	**Occurring in fine sand. An important food source for birds, fish and marine mammals**
Fish	Lesser weaver	*Trachinus vipera*	Specific to sand, where they lie buried subsurface
Ray	Thornback ray	*Raja clavata*	Residual population. Long-lived species
Fish	Plaice	*Pleuronectes platessa*	Generally found on sandy substrate. Common species

Note: species occurring within the N5a Development survey area are shown in **bold** font type.

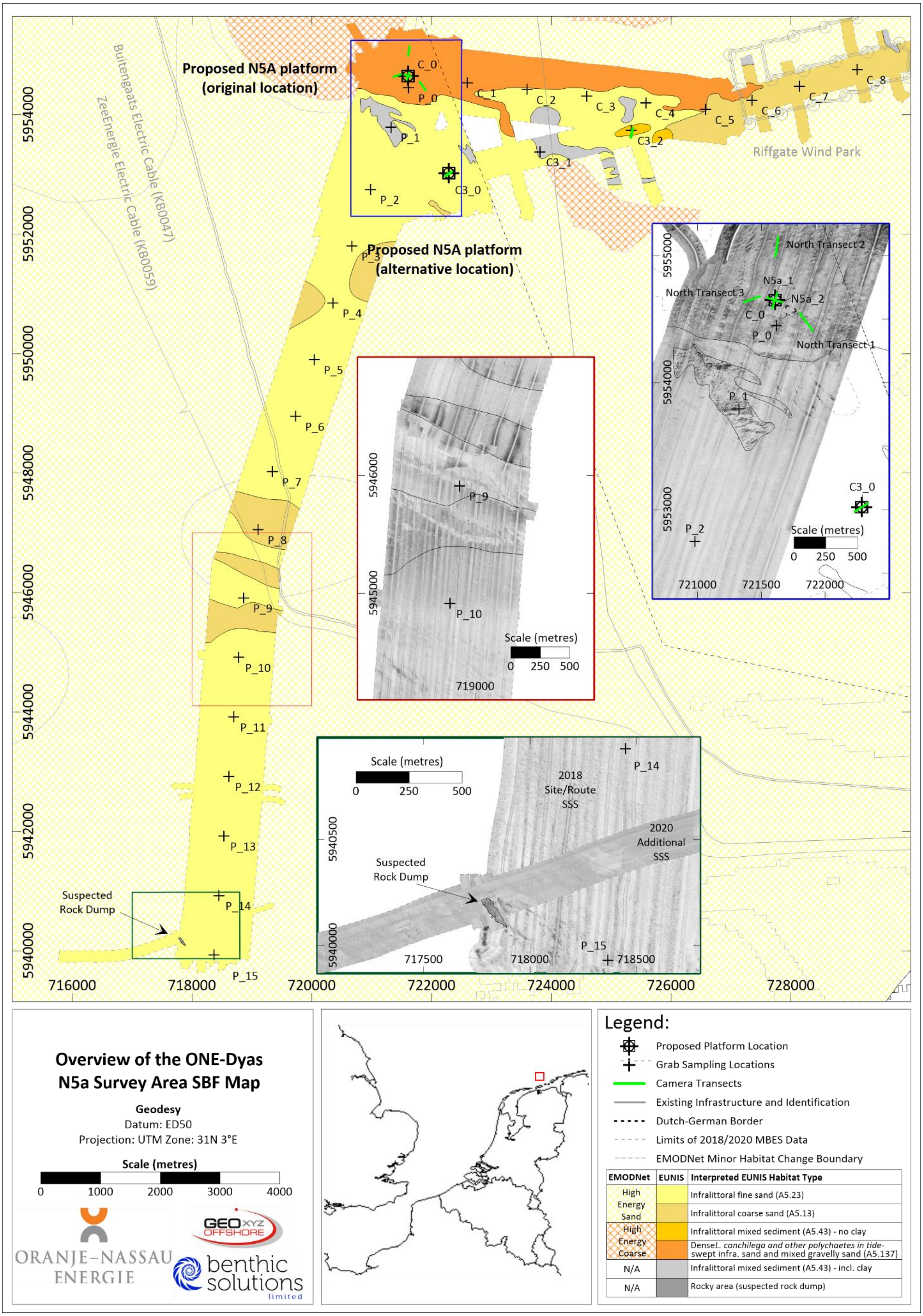


Figure 9: N5A Site and Route Habitat Distribution

4 CONCLUSION

The seabed sediment within the combined N5A site and route survey area ranged from a maximum of approximately 26.4m LAT at KP0.000 and 8.5m LAT at KP15.167 atop a rock dump protecting the existing tie-in point on the NGT pipeline. Both the N5A to NGT Pipeline (NP-001) tie-in route and N5A to Riffgat cable route were crossed by a series of natural troughs trending west-north-west to east-south-east.

The seabed features within the combined site and route survey area were interpreted from a combination of geophysical and environmental ground-truthing data to comprise six main seabed feature types:

- 'Fine sand and shell fragments' was the dominant sediment type across the combined survey area, including the area of the revised N5A to NGT Pipeline (NP-001) tie-in route between KP15 and KP15.167;
- 'Coarse sand and shell fragments' was delineated in a large area around the Riffgate Wind Park and in six smaller patches along the routes;
- 'Coarse sand with pebbles and cobbles' was present in two small patches midway along the N5A to Riffgate Wind Park cable route;
- 'Coarse sand and shell with a high density of sand mason worms and razor clams' was seen in a single large area along the northern edge of the N5A site and the N5A to Riffgate Wind Park cable route;
- 'Coarse sand and clay with pebbles and cobbles' was interpreted to be present in ten small patches within the N5A site and along the N5A to Riffgate Wind Park cable route.
- 'Rock dump' was evident overlying the NGT Pipeline (NP-001) tie-in point at KP15.167.

Based on review of the seabed camera and grab sampling data obtained during the N5A development site and route survey area, four EUNIS habitat classifications were assigned: 'Infralittoral fine sand' (A5.23), 'Infralittoral coarse sediment' (A5.13), 'Infralittoral Mixed Sediment' (A5.43) and 'Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand' (A5.137) and non-EUNIS 'Rock Dump' habitat of. Each of the assigned EUNIS habitat types corresponded to one of the interpreted seabed features types, with the exception of the 'infralittoral mixed sediment' (A5.43) EUNIS habitat, which was assigned to two seabed features types – 'Coarse sand with pebbles and cobbles' and 'Coarse sand and clay with pebbles and cobbles'.

Although a single patch of cobbles was observed within the survey area, there was deemed to be insufficient cover or elevation of cobbles to warrant consideration as a potential EC Habitats Directive Annex I stony reef habitat (after Irving, 2009).

The seabed sediments within the survey area were characterised by sand-dominated and supported several species listed by Jak et al., (2009) as being characteristic of the EC Habitats Directive Annex I permanently submerged sandbank habitat (subtype H1110_C). At present there is insufficient publicly available information to confirm classification of the survey area as the H1110_C habitat subtype, but it is possible that the survey area will be classified as such.

While *Lanice conchilega* beds are not currently listed as protected habitats, they are known to act as 'ecosystem engineers' (Rabaut et al., 2007) and have been suggested for inclusion as EC Habitats Directive Annex I habitats (Rabaut et al, 2009).

No other protected habitats or species were observed within the survey area, based on review of the acquired geophysical data and environmental ground-truthing by grab sampling and seabed photography.

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APPENDIX A – LOG SHEETS

Cast	Station	Sampler Used	Water Depth (m)	Time	Date	Volume Recovered (mm box depth)	Sample Name	Container Type and Quantity	Comments	Sediment Description/Stratification	Conspicuous Fauna/Comments
1	GRAB_P_0	Day grab	29	17:43:00	06/05/2019	85%	F1	2 x 3L bucket		shells, sand	*Lanice. conchilega, Asterias rubens, Nereis*
2	GRAB_P_0	DVV	29	18:20:00	06/05/2019	60% 50%	F2 PC	2 x 3L bucket Bags and jars		sand, small pieces of shells	*L. conchilega, A. rubens, Nereis*
3	GRAB_P_0	DVV	29	18:45:00	06/05/2019	60%	F3	3 x 3L bucket		sand, small pieces of shells	*L. conchilega, A. rubens, Nereis*
4	GRAB_P_1	DVV	27	20:12:00	06/05/2019	50% 50%	PC F1	1 x 3L bucket Bags and jars		clay	*L. conchilega*
5	GRAB_P_1	DVV	27	20:26:00	06/05/2019	N/S	N/S	N/S	Cobbles		
6	GRAB_P_1	DVV	27	20:40:00	06/05/2019	70% 50%	F2 F3	1 x 3L bucket 1 x 3L bucket		sand and clay	Polychaetes, Shell debris
7	GRAB_P_2	DVV	24	21:15:00	06/05/2019	50% 50%	PC F1	1 x 1L bucket Bags and jars		fine sand	*Echinocardium cordatum*, sandeel
8	GRAB_P_2	DVV	24	21:50:00	06/05/2019	60% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket	Flatfish in grab jaws, photo taken, discarded overboard. Grab seal not compromised so used for fauna	fine sand	Sandeel, polychaetes, flatfish poss. turbot
9	GRAB_P_3	DVV	23	22:56:00	06/05/2019	N/S	N/S	N/S	Block came down, strops broken, operations stopped		
10	GRAB_P_3	DVV	24	02:05:00	08/05/2019	50% 50%	PC F1	1 x 1L bucket Bags and jars	Weight added to arms	fine sand	*E. cordatum*
11	GRAB_P_3	DVV	24	02:15:00	08/05/2019	60% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		fine sand	Sandeel, *E. cordatum*
12	GRAB_P_4	DVV	22	02:45:00	08/05/2019	60% 50%	PC F1	1 x 1L bucket Bags and jars		fine sand	*L. conchilega*
13	GRAB_P_4	DVV	21	03:03:00	08/05/2019	50% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		fine sand	*L. conchilega*

Cast	Station	Sampler Used	Water Depth (m)	Time	Date	Volume Recovered (mm box depth)	Sample Name	Container Type and Quantity	Comments	Sediment Description/Stratification	Conspicuous Fauna/Comments
14	GRAB_P_5	DVV	20	03:31:00	08/05/2019	50% 50%	PC F1	1 x 1L bucket Bags and jars		Sand and shell	*E. cordatum*, razor clam
15	GRAB_P_5	DVV	20	03:42:00	08/05/2019	50% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		Sand and shell	*L. conchilega*
16	GRAB_P_6	DVV	21	04:29:00	08/05/2019	50% 50%	PC F1	1 x 1L bucket Bags and jars		Fine sand	*E. cordatum* (damaged)
17	GRAB_P_6	DVV	22	04:41:00	08/05/2019	50% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with minor shell fragments	Polychaetes, *Nereis*, *L. conchilega*, fish (damaged)
18	GRAB_P_7	DVV	22	05:09:00	08/05/2019	N/S	N/S	N/S	No sample, triggered but empty		
19	GRAB_P_7	DVV	22	05:22:00	08/05/2019	N/S	N/S	N/S	No sample, did not trigger		
20	GRAB_P_7	DVV	21	05:25:00	08/05/2019	N/S	N/S	N/S	No sample, did not trigger		
21	GRAB_P_7	DVV	21	05:27:00	08/05/2019	50% 50%	PC F1	1 x 1L bucket Bags and jars		Fine sand with minor shell debris	*L. conchilega*, polychaetes
22	GRAB_P_7	DVV	21	05:37:00	08/05/2019	50% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with minor shell debris, small amounts of mud/clay	Abundant *L. conchilega*, polychaetes
23	GRAB_P_8	DVV	21	06:01:00	08/05/2019	N/S	N/S	N/S			
24	GRAB_P_8	DVV	21	06:03:00	08/05/2019	N/S	N/S	N/S			
25	GRAB_P_8	DVV	20	06:04:00	08/05/2019	70% 70%	PC F1	1 x 5L bucket Bags and jars		Coarse sand with shell fragments	Polychaetes
26	GRAB_P_8	DVV	21	06:12:00	08/05/2019	70% 60%	F2 F3	1 x 5L bucket 1 x 5L bucket		Coarse sand with shell fragments	*L. conchilega*
27	GRAB_C_8	DVV	24	19:00:00	09/05/2019	80% 80%	PC F1	1 x 1L bucket Bags and jars		Coarse sand with shell fragments	*L. conchilega*
28	GRAB_C_8	DVV	24	19:15:00	09/05/2019	80% 80%	F2 F3	1 x 1L bucket 1 x 1L bucket		Coarse sand with shell fragments	*L. conchilega*
29	GRAB_C_7	DVV	24	19:30:00	09/05/2019	70%, 70%	PC F1	3 x 3L bucket Bags and jars		Coarse sand with shell fragments	No conspicuous fauna

Cast	Station	Sampler Used	Water Depth (m)	Time	Date	Volume Recovered (mm box depth)	Sample Name	Container Type and Quantity	Comments	Sediment Description/Stratification	Conspicuous Fauna/Comments
30	GRAB_C_7	DVV	24	19:45:00	09/05/2019	N/S	N/S	N/S	Deployed but no sample, not triggering		
31	GRAB_C_7	DVV	24	20:05:00	09/05/2019	70% 80%	F2 F3	2 x 5L bucket 2 x 5L bucket		Coarse sand with shell fragments	No conspicuous fauna
32	GRAB_C_6	DVV	24	20:27:00	09/05/2019	60% 80%	PC F1	1 x 3L bucket Bags and jars		Coarse sand with shell fragments	No conspicuous fauna
33	GRAB_C_6	DVV	24	21:05:00	09/05/2019	80%, 80%	F2 F3	1 x 3L bucket 1 x 3L bucket		Coarse sand with shell fragments	Urchin
34	GRAB_C_5	DVV	25	05:37:00	11/05/2019	40% 70%	PC F1	1 x 3L + 1x5L bucket Bags and jars		Coarse sand with shell fragments	Gobidae, *Asterias*, Lancelet. *L. conchilega*
35	GRAB_C_5	DVV	25	05:42:00	11/05/2019	70% 70%	F2 F3	2 x 5L bucket 1 x 5L + 1x 3L bucket		Coarse sand with shell fragments	*L. conchilega*, polychaetes, spatangoid
36	GRAB_C_4	DVV	28	06:40:00	11/05/2019	60% 60%	PC F1	1 x 1L bucket Bags and jars		Fine sand with shell debris	*L. conchilega*, polychaetes, spatangoid
37	GRAB_C_4	DVV	28	07:01:00	11/05/2019	70% 70%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with shell debris	*L. conchilega*, polychaetes, spatangoid
38	GRAB_C_3	DVV	28	07:29:00	11/05/2019	N/S	N/S	N/S	Did not trigger		
39	GRAB_C_3	DVV	28	07:36:00	11/05/2019	70% 70%	PC F1	1 x 1L bucket Bags and jars		Very fine sand with minor shell debris	*L. conchilega*, polychaetes
40	GRAB_C_3	DVV	28	07:47:00	11/05/2019	N/S	N/S	N/S	Triggered but no sample		
41	GRAB_C_3	DVV	28	07:49:00	11/05/2019	70% 70%	F2 F3	1 x 1L bucket 1 x 1L bucket		Very fine sand with minor shell debris and soft clay	Anemones, *L. conchilega*, polychaetes, A rubens, spatangoid
42	GRAB_C_2	DVV	27	08:15:00	11/05/2019	70% 70%	PC F1	1 x 5L bucket Bags and jars		Coarse sand and clay	*L conchilega* and polychaetes
43	GRAB_C_2	DVV	28	08:27:00	11/05/2019	70% 40%	F2 F3	1 x 5L bucket 1 x 3L bucket	Razor clams in jaws (F3)	Coarse sand	Razor clams, *L. conchilega*, polychaetes. Lancelet

Cast	Station	Sampler Used	Water Depth (m)	Time	Date	Volume Recovered (mm box depth)	Sample Name	Container Type and Quantity	Comments	Sediment Description/Stratification	Conspicuous Fauna/Comments
44	GRAB_C_1	DVV	28	08:55:00	11/05/2019	60% 60%	PC F1	1 x 3L + 1x5L bucket Bags and jars		Coarse sand and abundant shell debris	Lancelet and polychaetes
45	GRAB_C_1	DVV	28	09:04:00	11/05/2019	60% 40%	F2 F3	1 x 5L bucket 1 x 5L bucket	Razor clams in jaws (F3)	Coarse sand and abundant shell debris	*L. conchilega*, lancelet, polychaetes, porcelain crab
46	GRAB_C_0	DVV	29	09:32:00	11/05/2019	90% 90%	PC F1	2 x 5L bucket Bags and jars	Label for F2 in F1 bucket (2 of 2)	Coarse sand	*L. conchilega*, razor clams and polychaetes
47	GRAB_C_0	DVV	29	09:41:00	11/05/2019	90% 90%	F2 F3	2 x 5L bucket 2 x 5L bucket	Label for F3 in F2 bucket (1 of 2)	Coarse sand	*L. conchilega*, razor clams and polychaetes
48	GRAB_P_15	DVV	13	02:15:00	12/05/2019	60% 60%	PC F1	1 x 1L bucket Bags and jars		Fine sand with shell	Polychaetes
49	GRAB_P_15	DVV	13	02:20:00	12/05/2019	60% 60%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with shell	Polychaetes, sandeel
50	GRAB_P_14	DVV	14	03:05:00	12/05/2019	60% 60%	PC F1	1 x 3L bucket Bags and jars		Fine sand with shell	*Asterias*, Spatangoid, *Ophiura*
51	GRAB_P_14	DVV	14	03:10:00	12/05/2019	60% 60%	F2 F3	1 x 3L bucket 1 x 3L bucket		Fine sand with shell	Spatangoid, *Ophiura*
52	GRAB_P_13	DVV	16	03:30:00	12/05/2019	60% 60%	PC F1	1 x 1L bucket Bags and jars		Fine sand with minor shell debris	Polychaetes
53	GRAB_P_13	DVV	16	03:45:00	12/05/2019	60% 60%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with minor shell debris	*Nereis*, *L. conchilega*, *Ophiura*, Spatangoids
54	GRAB_P_12	DVV	16	04:32:00	12/05/2019	60% 60%	PC F1	1 x 3L bucket Bags and jars		Fine sand with shell debris	*Nereis*, *L. conchilega*, Spatangoids
55	GRAB_P_12	DVV	16	04:42:00	12/05/2019	60% 60%	F2 F3	1 x 3L bucket 1 x 3L bucket		Fine sand with shell debris	*Nereis*, *L. conchilega*, Spatangoids
56	GRAB_P_11	DVV	17	05:03:00	12/05/2019	70% 70%	PC F1	1 x 3L bucket Bags and jars		Fine sand with significant shell debris	*L. conchilega*
57	GRAB_P_11	DVV	17	05:13:00	12/05/2019	70% 70%	F2 F3	1 x 3L bucket 1 x 3L bucket		Fine sand with significant shell debris	*L. conchilega*
58	GRAB_P_10	DVV	17	05:35:00	12/05/2019	60% 60%	PC F1	1 x 1L bucket Bags and jars		Fine sand with shell debris	Polychaetes, *L. conchilega*, *Nereis*

Cast	Station	Sampler Used	Water Depth (m)	Time	Date	Volume Recovered (mm box depth)	Sample Name	Container Type and Quantity	Comments	Sediment Description/Stratification	Conspicuous Fauna/Comments
59	GRAB_P_10	DVV	17	05:44:00	12/05/2019	60% 60%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with shell debris	Polychaetes, *L. conchilega*
60	GRAB_P_9	DVV	19	06:05:00	12/05/2019	60% 60%	PC F1	1 x 3L bucket Bags and jars		Fine sand with shell debris	*Nereis*
61	GRAB_P_9	DVV	19	06:13:00	12/05/2019	60% 60%	F2 F3	1 x 3L bucket 1 x 3L bucket		Fine sand with shell debris	Polychaetes
62	GRAB_C3_0	DVV	24	22:43:00	14/05/2019	60% 60%	PC F1	1x1L bucket		Fine sand with shell debris	*E. cordatum*
63	GRAB_C3_0	DVV	24	22:59	14/05/2019	50% 50%	F2 F3	1 x 1L bucket 1 x 1L bucket		Fine sand with shell debris	*E. cordatum*
64	GRAB_C3_1	DVV	25	23:36:00	14/05/2019	50% 50%	PC F1	1 x 3L bucket Bags and jars		Fine sand with clay beneath	Polychaetes. Poss. piddock holes in clay but no piddocks evident
65	GRAB_C3_1	DVV	25	23:45:00	14/05/2019	50% 50%	F2 F3	1 x 3L bucket 1 x 3L bucket		Fine sand with clay beneath	Polychaetes. Poss. piddock holes in clay but no piddocks evident
66	GRAB_C3_2	DVV	25	00:13:00	15/05/2019	NS NS			Cobbles in jaws		
67	GRAB_C3_2	DVV	25	00:20:00	15/05/2019	50% 50%	PC F1	1 x 3L bucket Bags and jars		sandy gravel	Polychaetes hydroids
68	GRAB_C3_2	DVV	25	00:29:00	15/05/2019	50% NS	F2	1x5L bucket	Cobble in jaws of one bucket	sandy gravel	Polychaetes hydroids
69	GRAB_C3_2	DVV	25	00:36:00	15/05/2019	45%	F3	1x1L bucket	Cobble in jaws of one bucket	sandy gravel	Polychaetes hydroids

APPENDIX B – HABITAT ASSESSMENT

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
Grab_C_0				N5a_1_018.jpg, N5a_1_019.jpg, N5a_2_021.jpg, N5a_1_022.jpg	Coarse sand and shell fragments	*Asterias rubens*, *Lanice conchilega*	30	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
Grab_C_1	722598	5954539	11/05/19 02:56:48	Grab_C_1_005.jpg	Coarse sand and shell fragments with *Lanice conchilega* assemblages	*Asterias rubens*, *Liocarcinus* sp., *Lanice conchilega*, Decapoda	28	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	722599	5954538	11/05/19 02:57:27									
Grab_C_2	723694	5954422	11/05/19 03:28:13	Grab_C_2_002.jpg	Coarse sand and shell fragments with *Lanice conchilega* assemblages	*Asterias rubens*, *Liocarcinus* sp., *Lanice conchilega*, *Loligo vulgaris*	28	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	723596	5954422	11/05/19 03:29:04									
Grab_C_3	724589	5954311	11/05/19 04:08:03	Grab_C_3_003.jpg	Fine to medium sand ripples with shell fragments accumulated between ripples	*Asterias rubens*, *Liocarcinus* sp., *Lanice conchilega*	28	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	724590	5954310	11/05/19 04:10:35									
Grab_C_4	725582	5954199	11/05/19 04:34:40	Grab_C_4_002.jpg	Fine to medium sand ripples with shell fragments accumulated between ripples	*Asterias rubens*, *Lanice conchilega*, *Arenicola* sp., Decapoda	28	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	725581	5954200	11/05/19 04:37:18									
Grab_C_5	726576	5954086	11/05/19 05:01:59	Grab_C_5_002.jpg	Coarse sand ripples with small shell fragments accumulated between ripples	*Asterias rubens*, *Liocarcinus sp.*, *Lanice conchilega*, poss. *Callionymus lyra*	25	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	726573	5954088	11/05/19 05:05:12									

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
Grab_C_6	727352	5954243	09/05/19 17:05:54	Grab_C_6_002.jpg	Coarse sand ripples with small shell fragments accumulated between ripples	*Lanice conchilega*	24	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	727353	5954242	09/05/19 17:06:30									
Grab_C_7	728147	5954477	09/05/19 17:33:39	Grab_C_7_004.jpg	Coarse sand ripples with small shell fragments accumulated between ripples	*Lanice conchilega*, *Asterias rubens*	24	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	728148	5954477	09/05/19 17:34:26									
Grab_C_8	729105	5954755	09/05/19 18:00:57	Grab_C_8_005.jpg	Fine to medium sand ripples with small shell fragments accumulated between ripples	Poss. Gobiidae, *Asterias rubens*, *Lanice conchilega*	24	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	729108	5954757	09/05/19 18:01:58									
Grab_C3_0	722231	5952984	14/05/19 21:51:01	Grab_C3_0_002.jpg	Fine to medium sand ripples with small shell fragments accumulated between ripples	*Asterias rubens*, *Lanice conchilega*, Decapoda, *Ammodytes* sp., *Corystes cassivelaunus*, Gobiidae, *Ophiura ophiura*	24	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	722336	5953047	14/05/19 22:00:16									
Grab_C3_1	723807	5953379	14/05/19 21:23:19	Grab_C3_1_001.jpg	Coarse shelly sand with partially buried cobbles and slight sand ripples	Pleuronectiform, *Asterias rubens*	24	n/a	n/a	n/a	n/a	Infralittoral mixed sediment (A5.43) – incl. clay
	723808	5953379	14/05/19 21:24:23									
Grab_C3_2	725366	5953610	14/05/19 20:46:00	Grab_C3_2_0014jpg	Fine to medium sand ripples with small shell fragments that have accumulated between ripples	*Lanice conchilega*, *Asterias rubens*, poss. *Callionymus lyra*, Pleuronectiformes, *Ammodytes* sp., Paguridae, Decapoda, *Metridium senile*, *Cancer pagurus*, Actiniaria, *Liocarcinus*	25	Not a Reef	Not a Reef	Not Reef	Not a Reef	Infralittoral fine sand (A5.23)
	725352	5953670	14/05/19 20:51:34									
	725352	5953670	14/05/19 20:51:35	Grab_C3_2_020.jpg	Cobbles overlying coarse sand with occasional boulders			25	10	Low	Low	Infralittoral mixed sediment (A5.43) - no clay
	725347	5953687	14/05/2019 20:52:38									

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
	725347	5953688	14/05/2019 20:52:39	Grab_C3_2_021.jpg	Coarse sand with cobbles	sp., Ceriathidae, *Sertularia* sp.		10	5	Not a Reef	Not a Reef	Infralittoral mixed sediment (A5.43) - no clay
	725343	5953712	14/05/2019 20:54:08									
	725343	5953712	14/05/2019 20:54:09	Grab_C3_2_028.jpg	Occasional cobble over lying coarse sand and infrequent boulders			10	5	Not a Reef	Not a Reef	Infralittoral mixed sediment (A5.43) - no clay
	725333	5953755	14/05/2019 20:57:02									
	725333	5953755	14/05/2019 20:57:03	Grab_C3_2_035.jpg	Cobbles overlying coarse sand with occasional boulders			30	20	Low	Low	Infralittoral mixed sediment (A5.43) - no clay
	725326	5953785	14/05/2019 20:58:50									
Grab_P_0	721647	5954431	02/05/19 17:15:09	Grab_P_0_021.jpg	Coarse sand littered with shell fragments and *Lanice conchilega* assemblages	*Asterias rubens, Lanice conchilega*, Decapoda, Paguridae, Actiniaria, Gobiidae, Cerianthidae	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721595	5954473	02/05/19 17:22:22									
Grab_P_1	721323	5953795	02/05/19 19:00:12	Grab_P_1_006.jpg	Coarse sand with cobbles	Cerianthidae, *Asterias rubens*, Bryozoa	27	n/a	n/a	n/a	n/a	Infralittoral mixed sediment (A5.43) – incl. clay
	721325	5953794	02/05/19 19:01:32									
Grab_P_2	720981	5952753	02/05/19 20:00:37	Grab_P_2_002.jpg	Fine to medium shelly sand with sand ripples	*Lanice conchilega*, *Corystes cassivelaunus*	24	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	720980	5952752	02/05/19 20:02:04									
Grab_P_3	720668	5951799	06/05/19 15:43:57	Grab_P_3_007.jpg	Fine to medium sand forming ripples	*Corystes cassivelaunus*, *Asterias rubens*, *Lanice conchilega*	24	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	720666	5951799	06/05/19 15:47:09									
Grab_P_4	720245	5950807	03/05/19 15:07:42	Grab_P_4_005.jpg	Fine to medium sand formed into sand ripples	Asteroidea, Ophiuroid	22	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	720355	5950855	03/05/19 15:10:32									

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
Grab_P_5	720036	5949903	03/05/19 13:36:49	Grab_P_5_004.jpg	Fine to medium shelly sand with rare cobbles	Paguridae, *Lanice conchilega*, *Asterias rubens*	20	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	720036	5949903	03/05/19 13:38:12									
Grab_P_6	719725	5948952	03/05/19 13:04:18	Grab_P_6_004.jpg	Fine to medium sand with irregular ripples	*Lanice conchilega*, Pleuronectiform	22	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	719729	5948948	03/05/19 13:08:36									
Grab_P_7	719412	5948000	03/05/19 11:18:23	Grab_P_7_005.jpg	Fine to medium sand with irregular ripples	*Lanice conchilega*, *Callionymus lyra*, Ophiuroid	21	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	719411	5948003	03/05/19 11:22:22									
Grab_P_8	719099	5947048	03/05/19 12:05:32	Grab_P_8_005.jpg	Coarse sand and shell debris with irregular ripples	*Lanice conchilega*	21	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	719094	5947051	03/05/19 12:07:34									
Grab_P_9	718861	5945913	11/05/19 22:31:48	Grab_P_9_002.jpg	Coarse sand and shell debris with irregular ripples	*Asterias rubens*, *Lanice conchilega*, *Corystes cassivelaunus*, Actinopterygii	19	n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	718862	5945911	11/05/19 22:33:08									
Grab_P_10	718778	5944917	11/05/19 23:01:57	Grab_P_10_003.jpg	Fine to medium sand	*Asterias rubens*, *Lanice conchilega*	17	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	718778	5944917	11/05/19 23:04:14									
Grab_P_11	718697	5943920	11/05/19 23:30:17	Grab_P_11_009.jpg	Fine to medium sand and shell debris with irregular ripples	Brachyura, *Lanice conchilega*	17	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	718697	5943920	11/05/19 23:32:11									
Grab_P_12	718614	5942925	11/05/19 23:58:12	Grab_P_12_002.jpg	Fine to medium sand and shell debris with irregular ripples	*Asterias rubens*, *Lanice conchilega*, *Callionymus lyra*, Gobiidae, *Actiniaria*, Brachyura, *Cancer pagurus*, *Liocarcinus sp.*	16	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	718615	5942922	12/05/19 00:00:03									

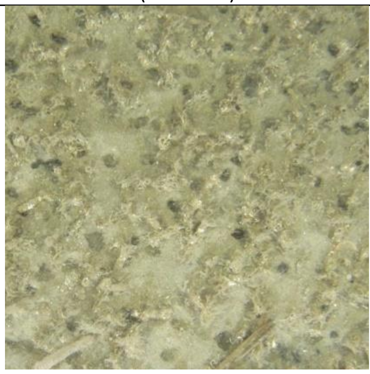
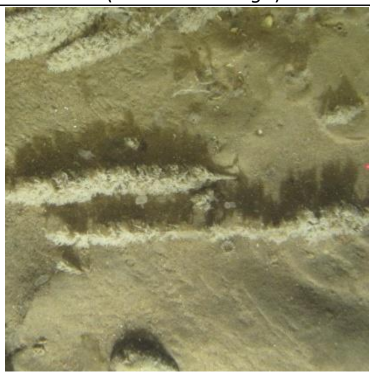
ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
Grab_P_13	718531	5941926	12/05/19 00:30:02	Grab_P_13_005.jpg	Fine to medium sand with irregular ripples	*Asterias rubens*, Ophiuroids, *Lanice conchilega*	16	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	718533	5941928	12/05/19 00:31:30									
Grab_P_14			No visibility									
Grab_P_15	718366	5939934	12/05/19 01:53:30	Grab_P_15_005.jpg	Fine to medium sand with irregular ripples	*Lanice conchilega*, Actinopterygii	13	n/a	n/a	n/a	n/a	Infralittoral fine sand (A5.23)
	718366	5939933	12/05/19 01:55:09									
N5a_1	721585	5954589	11/05/19 01:38:04	N5a_1_014.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed	*Lanice conchilega*, *Ensis* 'burrows', *Leptothecata*, *Actiniaria*, *Cancer pagurus*, *Callionymus lyra*, Paguridae, Actinopterygii, Sepiida, Pleuronectiform, Brachyura, *Sepiola* spp., *Cancer pagurus*, *Metridium senile*, *Ensis* sp., *Liocarcinus sp.*, Cerianthidae	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721626	5954710	11/05/19 01:46:42									
N5a_2	721669	5954631	11/05/19 01:16:25	N5a_2_002.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed	*Asterias rubens*, *Lanice conchilega*, *Cancer pagurus*, Actiniaria, Paguridae, *Ensis sp.*, *Cancer pagurus*, *Pagurus bernhardus*, Brachyura, *Callionymus lyra*, *Metridium senile*,	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721555	5954667	11/05/19 01:24:59									
	721554	5954667	11/05/19 01:25:00	N5a_2_038.jpg				n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
	721552	5954668	11/05/19 01:25:15		Large boulder surrounded by Ensis shells	*Liocarcinus sp.*, Cerianthidae						swept infralittoral sand and mixed gravelly sand (A5.137)
	721551	5954668	11/05/19 01:25:16	N5a_2_039.jpg	Coarse sand ripples			n/a	n/a	n/a	n/a	Infralittoral coarse Sediment (A5.13)
	721544	5954669	11/05/19 01:25:39									
North Transect 1	721487	5954681	11/05/19 00:49:09	N_T_1_002.jpg	Slightly gravelly/shelly coarse sand forming irregular ripples. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed	*Asterias rubens*, *Lanice conchilega*, *Cancer pagurus*, *Pagurus bernhardus*, Actiniaria, Paguridae, *Ensis* sp., Brachyura, Actinopterygii, *Cancer pagurus*, Pleuronectiform, *Limanda*, *Liocarcinus* sp., Cerianthidae	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721425	5954656	11/05/19 00:55:02									
	721425	5954656	11/05/19 00:55:03	N_T_1_021.jpg	Dense aggregations of *Lanice conchilega*, *Asterias rubens* and *Ensis* shells on gravelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed.			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721392	5954643	11/05/19 00:57:24									
	721391	5954643	11/05/19 00:57:25	N_T_1_028.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721363	5954633	11/05/19 00:59:20									

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
North Transect 2	721609	5954992	11/05/19 00:06:16	N_T_2_003.jpg	Slightly gravelly/shelly coarse sand forming irregular ripples. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed	*Asterias rubens, Lanice conchilega, Cancer pagurus, Pagurus bernhardus, Cancer pagurus, Pleuronectiform, Callionymus lyra, Bachyura, Actiniaria, Sepiidae, Liocarcinus sp., Ceriantthidae*	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721618	5955031	11/05/19 00:10:55									
	721617	5955032	11/05/19 00:10:56	N_T_2_014.jpg	Gravelly/shelly coarse sand forming irregular ripples. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721625	5955086	11/05/19 00:14:33									
	721625	5955086	11/05/19 00:14:34	N_T_2_038.jpg	Dense aggregations of *Lanice conchilega*, *Asterias rubens* and *Ensis* shells on gravelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed.			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721631	5955141	11/05/19 00:18:28									
	721631	5955142	11/05/19 00:18:29	N_T_2_041.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721632	5955153	11/05/19 00:19:05									

ED50, UTM 31N, CM 3° E												
Station	Easting (m)	Northing (m)	Date & Time	Example Photograph (file name)	Sediment type	Conspicuous fauna	Depth (m)	Stony Reefiness (After Irving 2009)			Overall Reef Structure	EUNIS Habitat Classification with SBF/Habitat Map Colour Code
								Composition (% cover of cobbles/ boulders)	Elevation (of cobbles/ boulders in cm)	Reef Structure Matrix		
North Transect 3	721902	5954408	11/05/19 02:04:47	N_T_3_010.jpg	Dense aggregations of *Lanice conchilega*, *Asterias rubens* and *Ensis* shells on gravelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed.	*Asterias rubens, Lanice conchilega, Cancer pagurus, Pagurus bernhardus, Cancer pagurus, Pleuronectiform, Actiniaria, Gobiidae, Paguridea, Ensis sp., Limanda, Metridium senile, Liocarcinus sp., Eutrigla gurnardus, Ceriantheidae*	29	n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721888	5954432	11/05/19 02:07:32									
	721887	5954432	11/05/19 02:07:33	N_T_3_018.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721865	5954461	11/05/19 02:09:55									
	721865	5954461	11/05/19 02:09:56	N_T_3_039.jpg	Dense aggregations of *Lanice conchilega*, *Asterias rubens* and *Ensis* shells on gravelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed.			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721824	5954518	11/05/19 02:14:38									
	721823	5954519	11/05/19 02:14:39	N_T_3_050.jpg	Slightly gravelly/shelly coarse sand. 'Burrows' formed by *Ensis* retracting below surface when the camera sled comes into contact with the seabed. Infrequent boulders.			n/a	n/a	n/a	n/a	Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand (A5.137)
	721801	5954551	11/05/19 02:17:16									

APPENDIX C – CONSPICUOUS SPECIES EXAMPLES FROM SEABED PHOTOGRAPHY

Examples of Conspicuous Fauna		
 Common Starfish (*Asterias rubens*)	 Atlantic Jackknife Clam (*Ensis leei*)	 Swimming Crab (*Liocarcinus* sp.)
 The Edible Crab (*Cancer pagurus*)	 Sand mason worm (*Lanice conchilega*)	 Burrowing anemones (Cerianthidae)
 Hermit Crab (Paguridae)	 Hydroids (*Sertularia*)	 Barnacles on an Edible Crab (Cirripedia and *Cancer pagurus*)
 Sand Eel (*Ammodytes sp.*)	 Burrowing Brittlestar (Ophiuroid)	 Common Dragonet (*Callionymus lyra*)

APPENDIX D – SAMPLE AND SEABED PHOTOGRAPHS

Habitat Summary Information: Grab_P_0

Survey Area: N5a Pipeline

No. of Stills: 27 | **Mins of Video: 7** | **Track Length: 70m**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals. Investigating area of mixed reflectivity sediment.

Analogue Interpretation

Variable mixed reflectivity with many raised areas.

Sediment Description

Coarse sand littered with shell fragments and lanice conchilega assemblages.

Conspicuous Fauna

Cnidaria: Actiniaria sp., *Cerianthus* sp., Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** Paguridae sp. , Decapoda sp. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** Gobiidae sp.

Grab_P_0_006.JPG

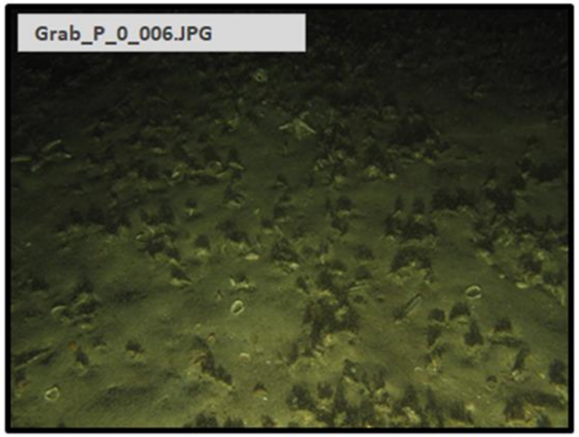


Photo Position: 721647 mE, 5954429 mN

Grab_P_0_013.JPG

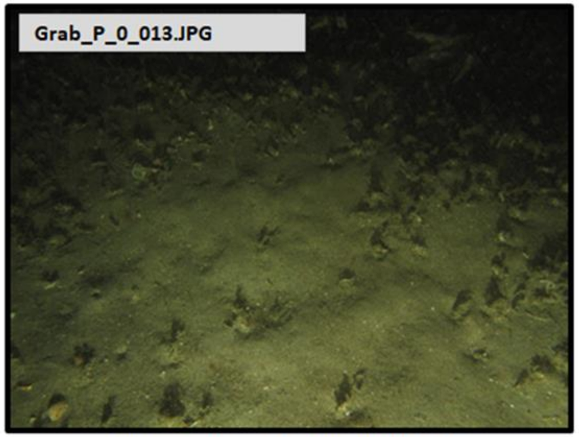


Photo Position: 721634 mE, 5954446 mN

Grab_P_0_018.JPG

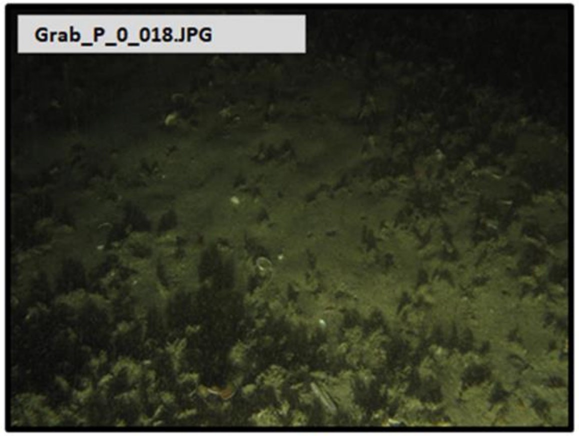


Photo Position: 721620 mE, 5954456 mN

Grab_P_0_024.JPG

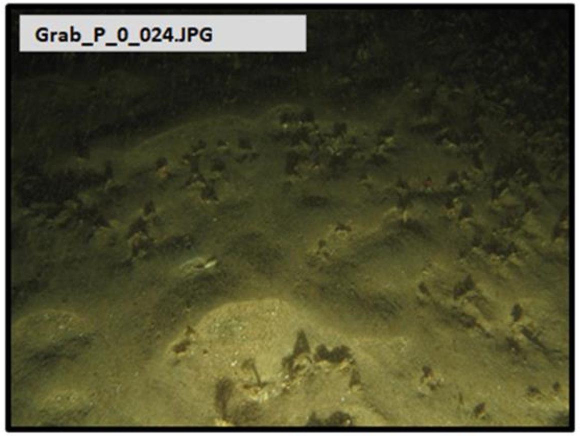
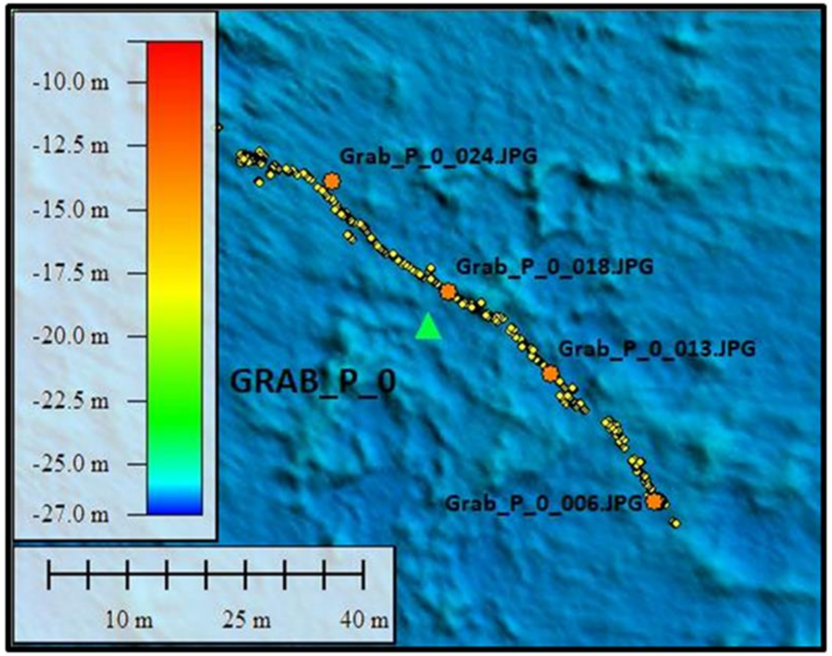


Photo Position: 721606 mE, 5954470 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

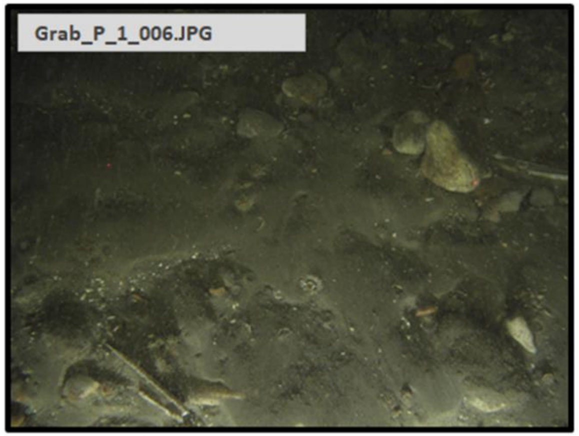


Photo Position: 721325 mE, 5953794 mN

Habitat Summary Information: Grab_P_01

Survey Area: N5a Pipeline

No. of Stills: 1 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria

Moved from KP in order to investigate area of high reflectivity sediment.

Analogue Interpretation

Area of mixed high reflectivity.

Sediment Description

Coarse sand with cobbles.

Conspicuous Fauna

Cnidaria: *Cerianthus* sp. **Echinodermata:** *Asterias rubens* (Common starfish). **Bryozoa:** Bryozoa sp.

Only one image taken

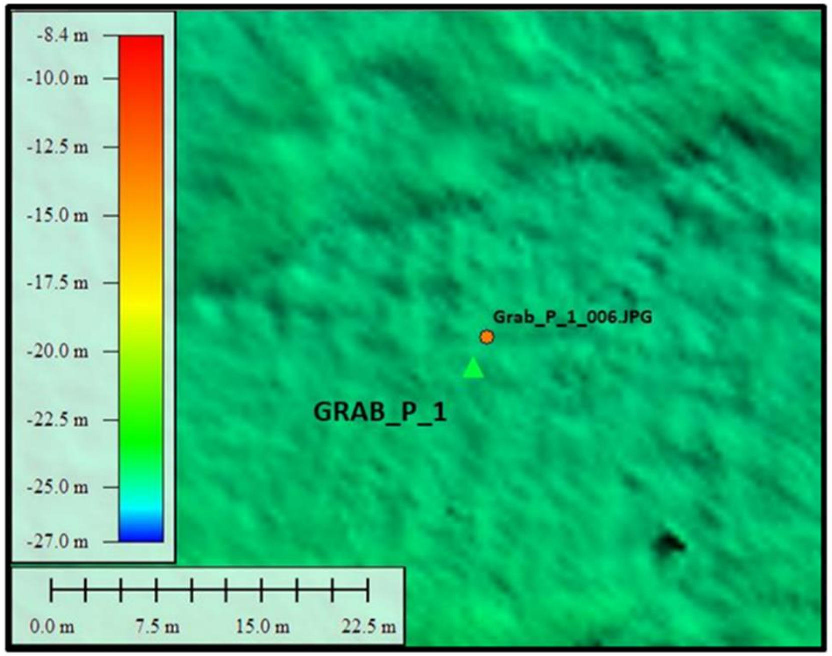
Photo Position: 0 mE, 0 mN

Only one image taken

Photo Position: 0 mE, 0 mN

Only one image taken

Photo Position: 0 mE, 0 mN



Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_P_02

Survey Area: N5a Pipeline

No. of Stills: 5 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Low reflectivity.

Sediment Description
Coarse shelly sand with sand ribble bedform.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Corystes cassivelaunus* (Masked crab).

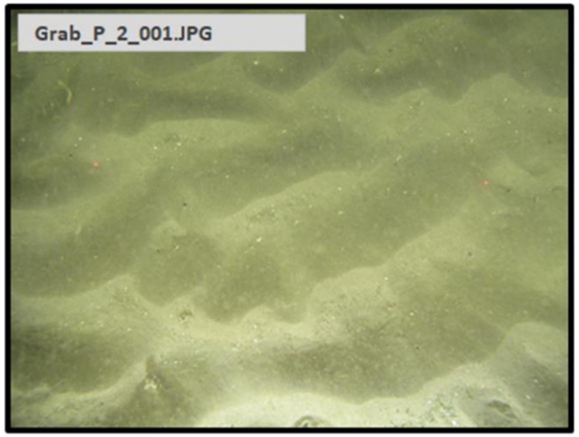


Photo Position: 720980 mE, 5952753 mN

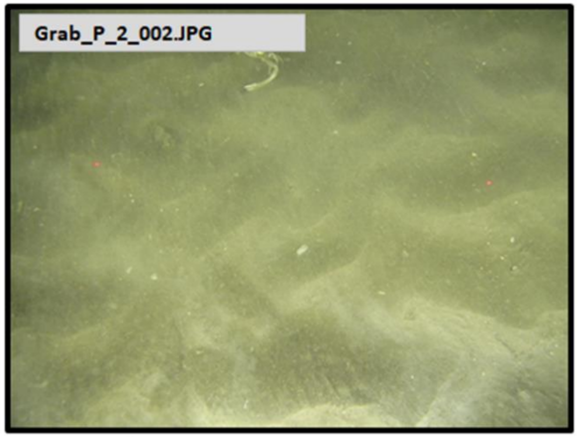


Photo Position: 720979 mE, 5952754 mN

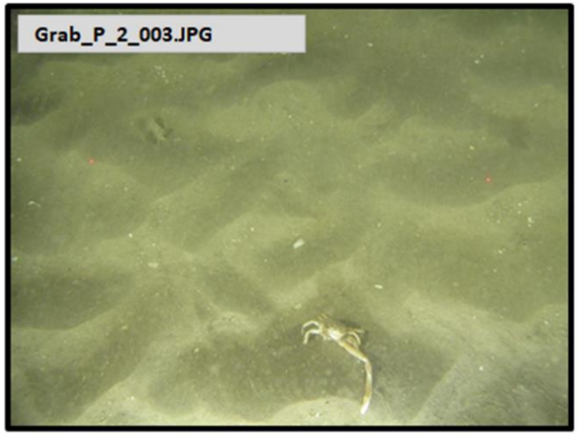


Photo Position: 720977 mE, 5952755 mN

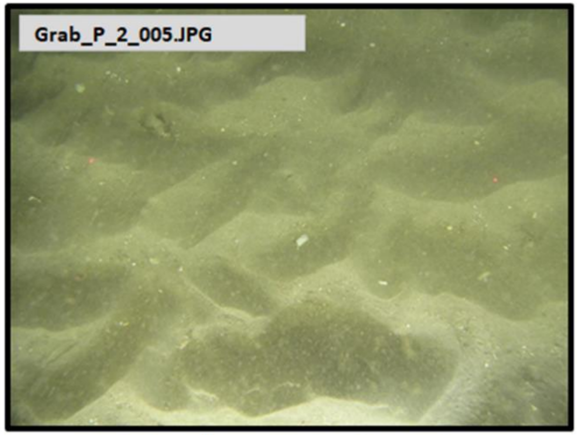
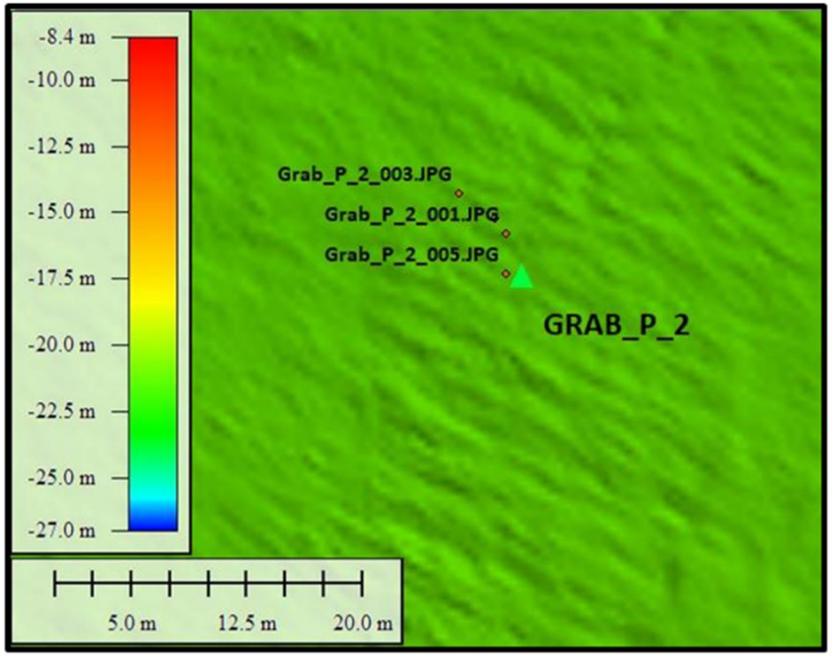
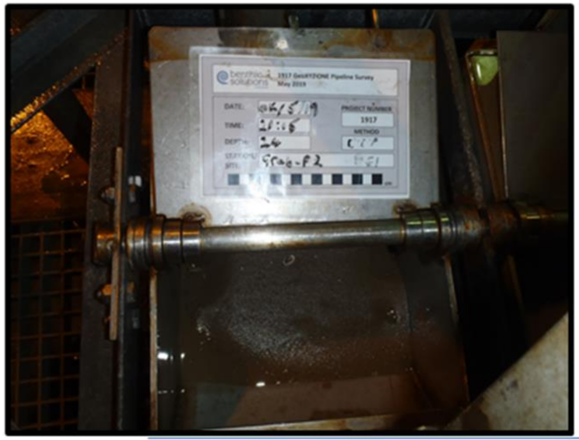


Photo Position: 720980 mE, 5952750 mN





Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_P_03

Survey Area: N5a Pipeline

No. of Stills: 10 **Mins of Video: 3** **Track Length: DDV**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity.

Sediment Description

Coarse sand forming ripples.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Corystes cassivelaunus* (Masked crab). **Echinodermata:** *Asterias rubens* (Common starfish).

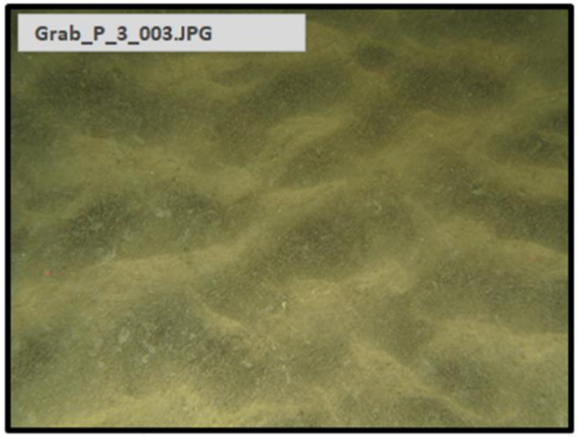


Photo Position: 720668 mE, 5951799 mN

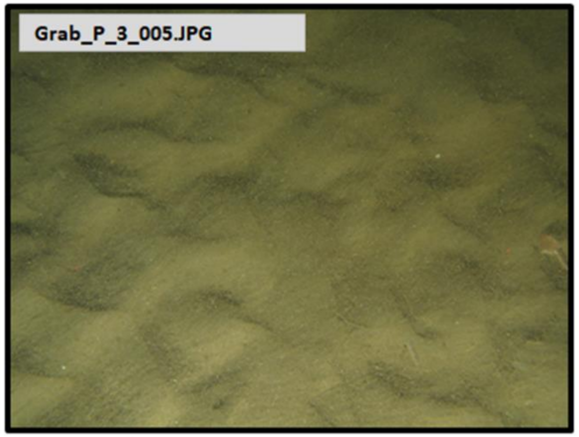


Photo Position: 720664 mE, 5951796 mN

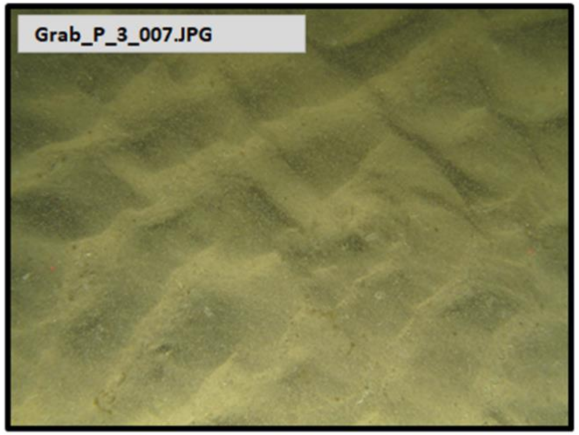


Photo Position: 720664 mE, 5951795 mN

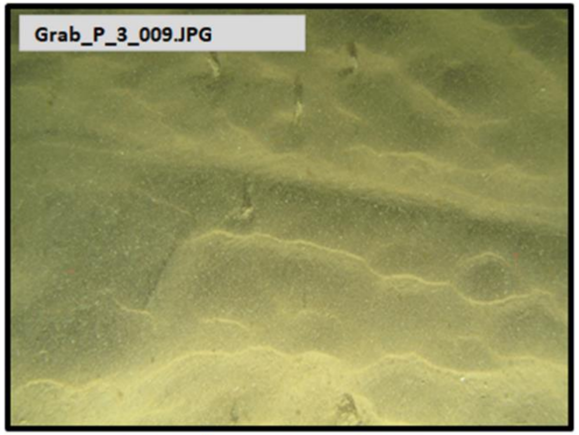
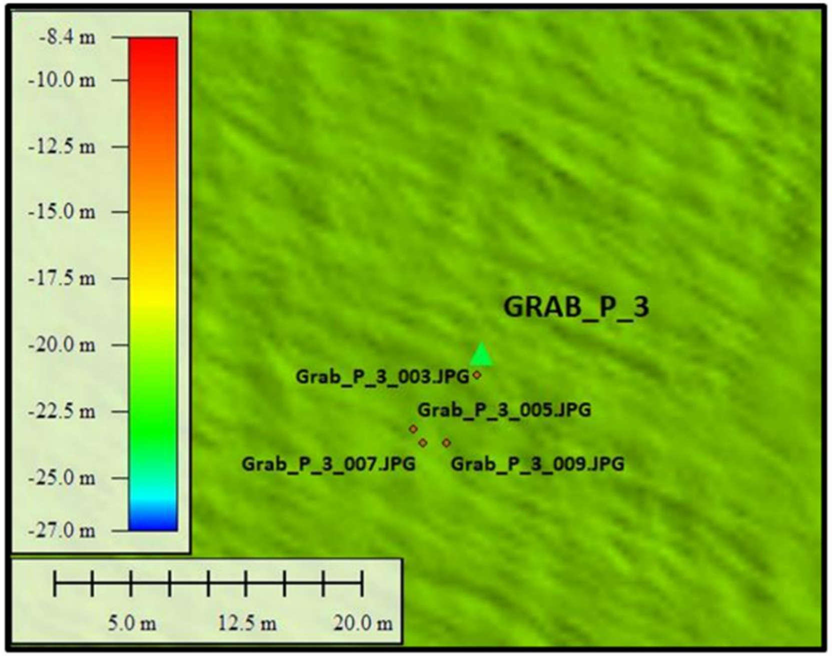


Photo Position: 720666 mE, 5951795 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

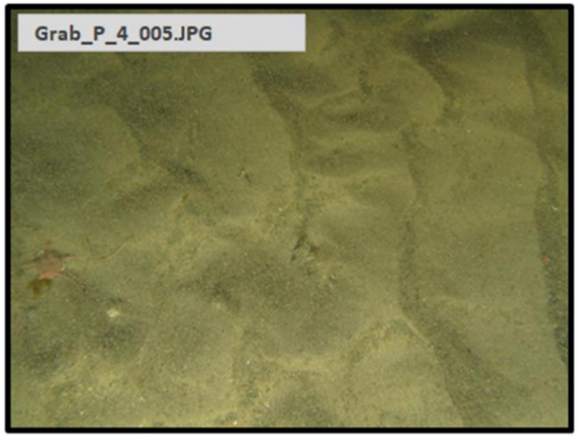


Photo Position: 720356 mE, 5950850 mN

Habitat Summary Information: Grab_P_04

Survey Area: N5a Pipeline

No. of Stills: 10 | Mins of Video: 3 | Track Length: DDV

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Area of variable reflectivity indicating rippling.

Sediment Description
Coarse sand formed into sand ripples.

Conspicuous Fauna
Echinodermata: *Asterias rubens* (Common starfish), Ophiurida sp.

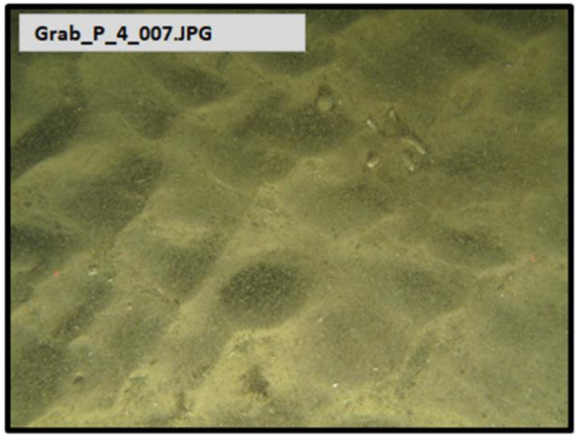


Photo Position: 720355 mE, 5950850 mN

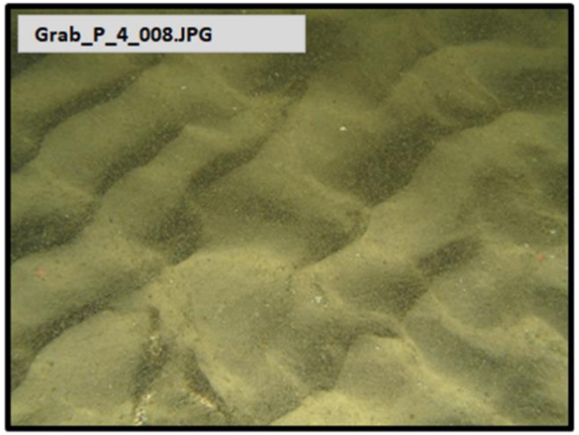
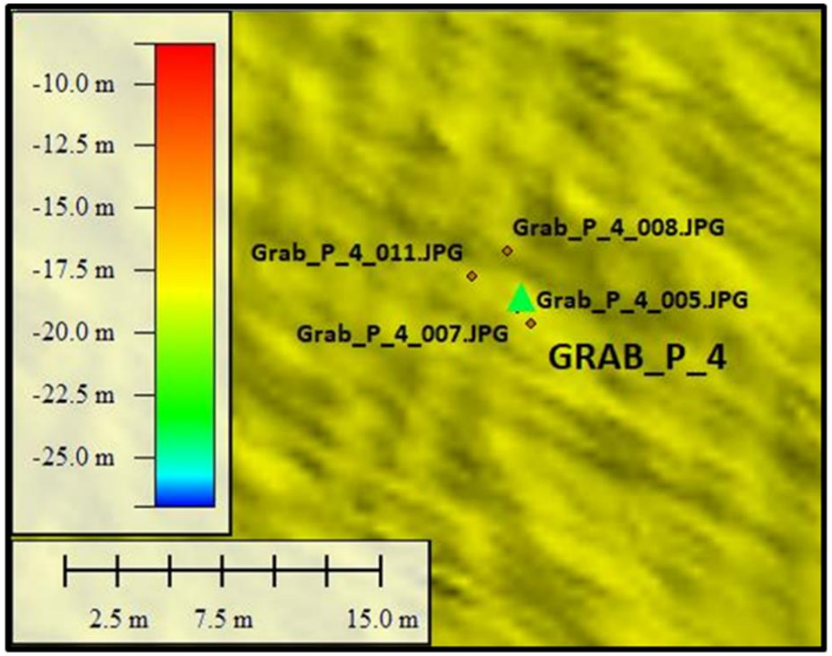


Photo Position: 720355 mE, 5950853 mN



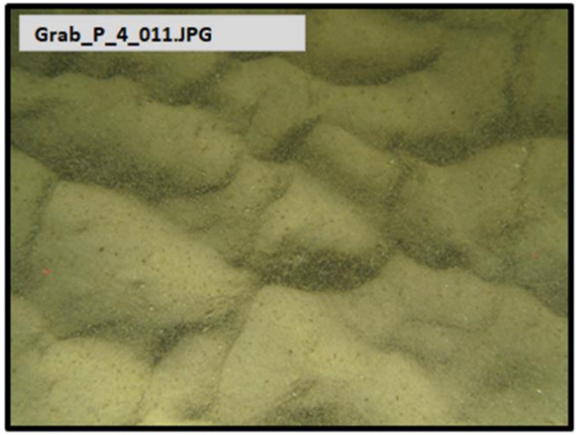


Photo Position: 720353 mE, 5950852 mN

Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_P_05

Survey Area: N5a Pipeline

No. of Stills: 16 **Mins of Video: 2** **Track Length: DDV**

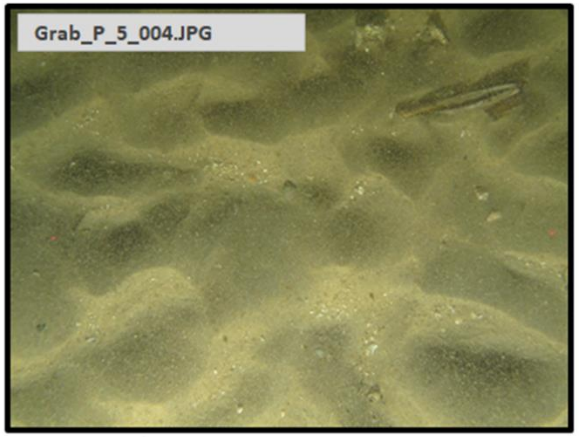


Photo Position: 720039 mE, 5949902 mN

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Area of low, variable reflectivity.

Sediment Description

Coarse shelly sand with rare cobbles.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** Paguridae sp. **Echinodermata:** *Asterias rubens* (Common starfish).

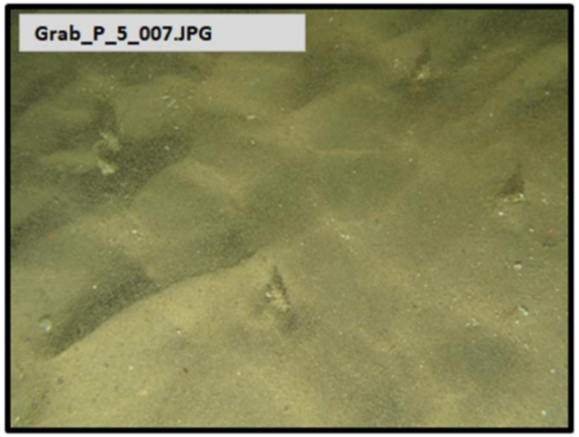


Photo Position: 720044 mE, 5949893 mN

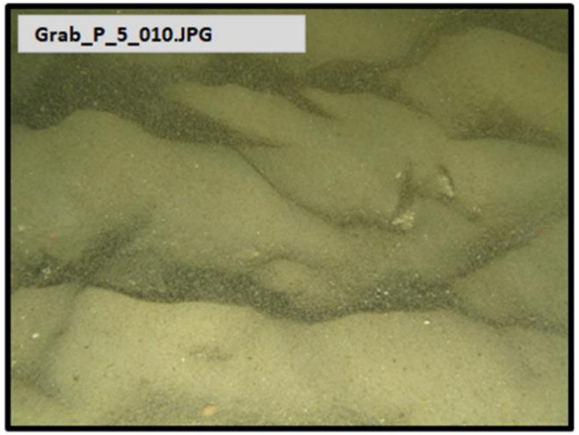
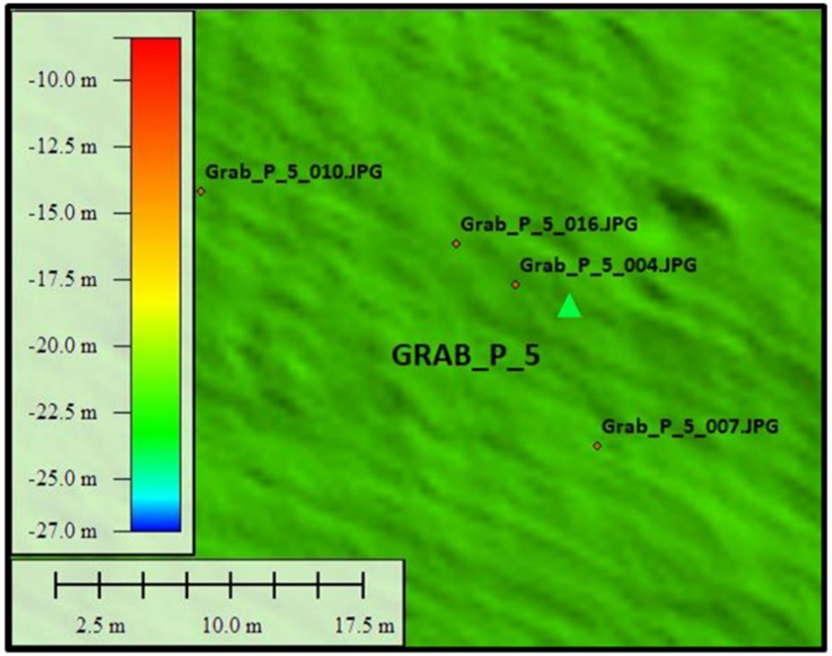


Photo Position: 720021 mE, 5949907 mN



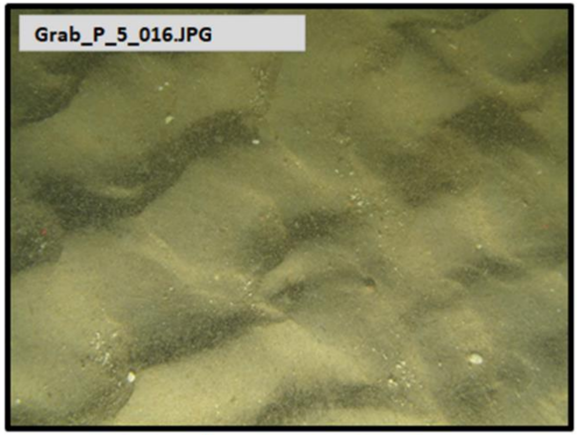


Photo Position: 720036 mE, 5949904 mN

Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_P_06

Survey Area: N5a Pipeline

No. of Stills: 12 | Mins of Video: 4 | Track Length: DDV

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Area of slightly variable reflectivity.

Sediment Description
Coarse sand with irregular ripples.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Chordata:** Pleuronectiformes sp.

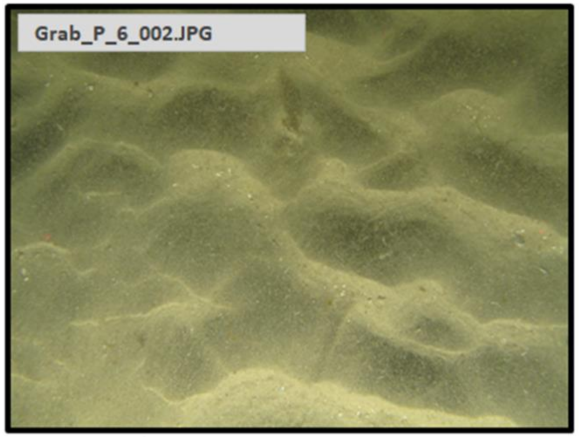


Photo Position: 719727 mE, 5948952 mN

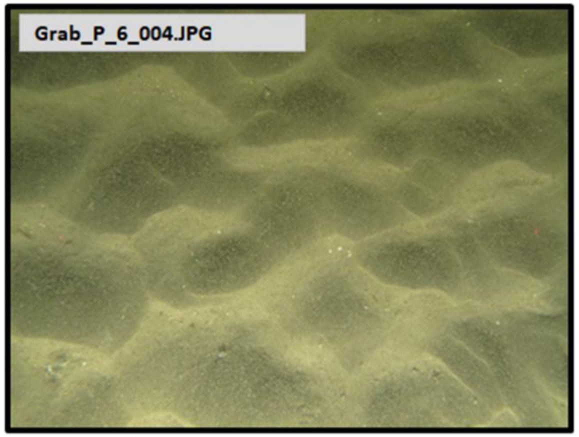


Photo Position: 719728 mE, 5948952 mN

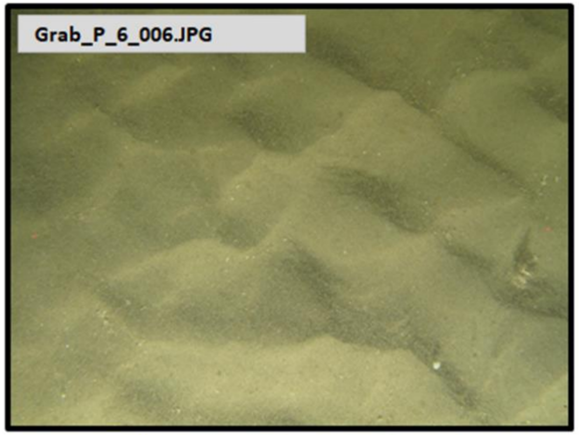


Photo Position: 719688 mE, 5948930 mN

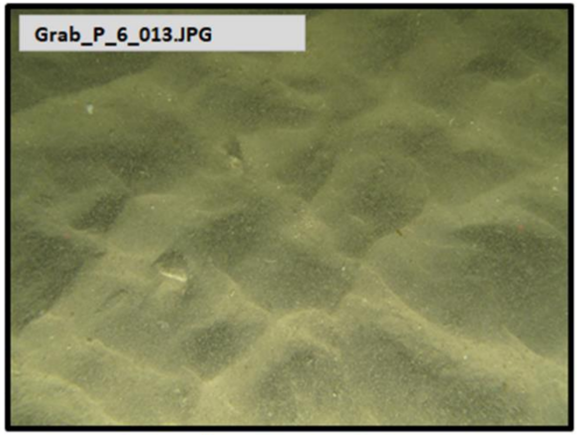
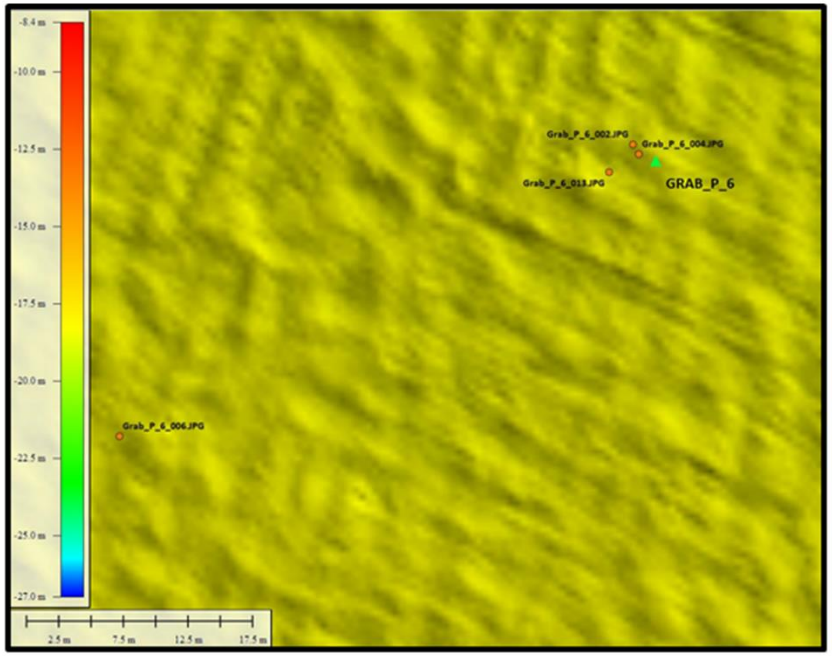


Photo Position: 719726 mE, 5948950 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_P_07

Survey Area: N5a Pipeline

No. of Stills: 7 **Mins of Video: 4** **Track Length: DDV**

Site Selection Criteria

Moved from KP to investigate mixed reflectivity sediment.

Analogue Interpretation

Area of variable reflectivity with scars in seabed.

Sediment Description

Coarse sand with irregular ripples.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** Ophiurida sp. **Chordata:** *Callionymus lyra* (Common dragonet).

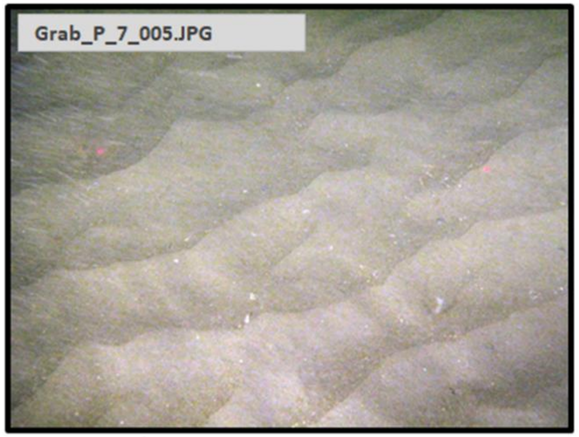


Photo Position: 719408 mE, 5948019 mN

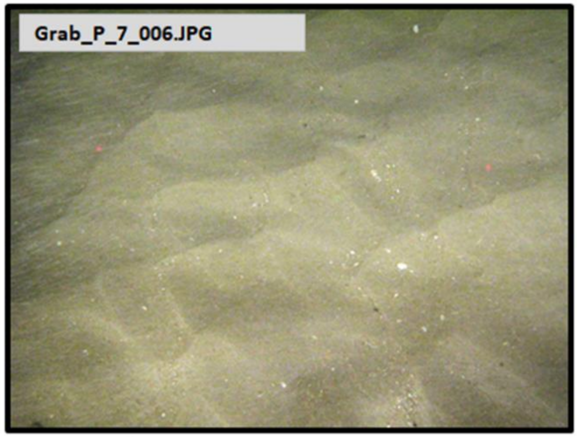


Photo Position: 719411 mE, 5948002 mN

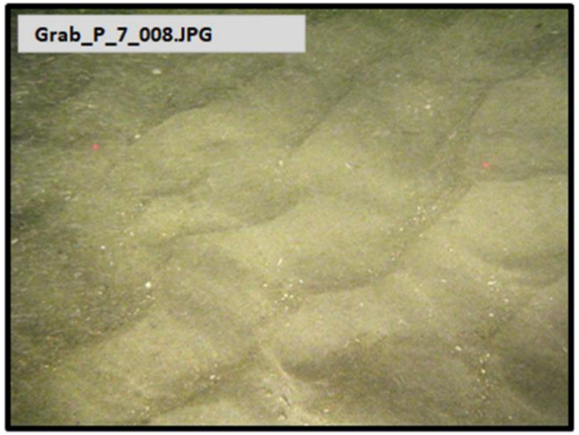
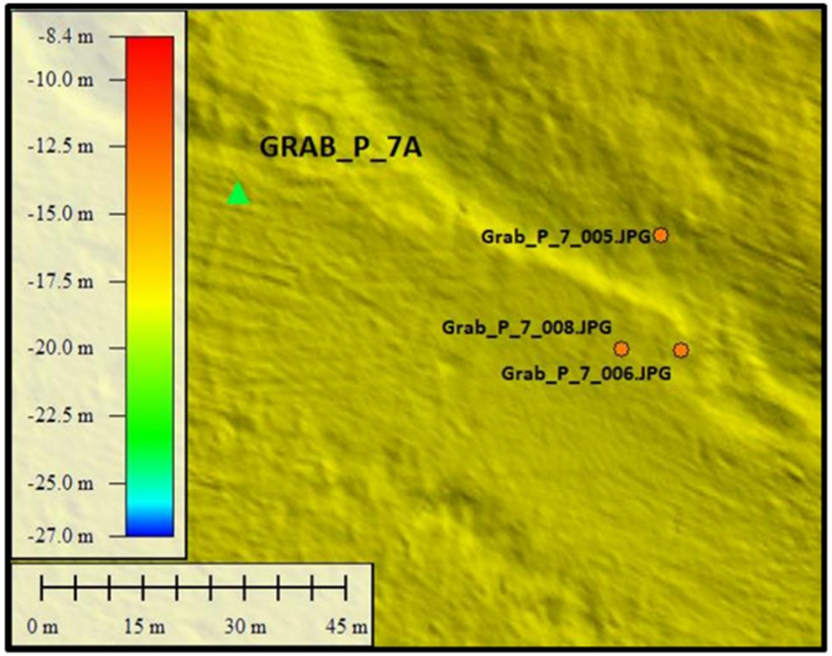
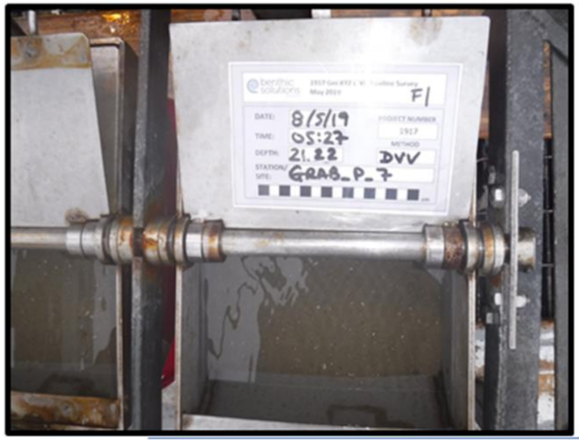


Photo Position: 719403 mE, 5948002 mN



Only 3 good quality seabed images



Sediment Example Image

Sieved Sample Image

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Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

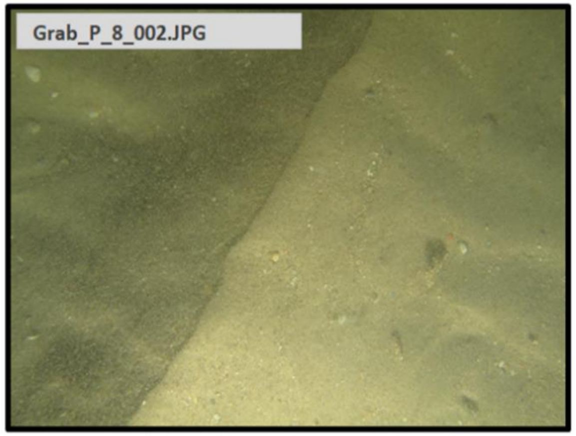


Photo Position: 719097 mE, 5947051 mN

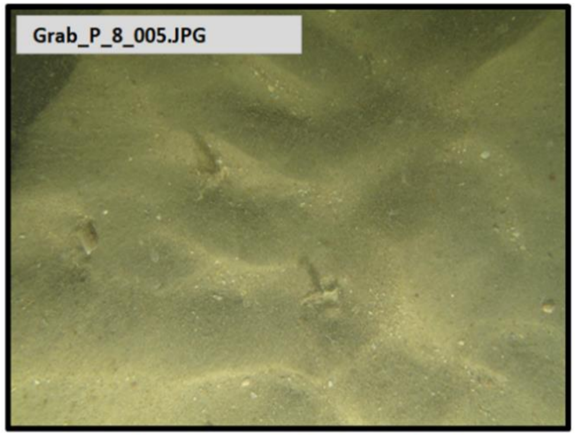


Photo Position: 719125 mE, 5947049 mN

Habitat Summary Information: Grab_P_08

Survey Area: N5a Pipeline

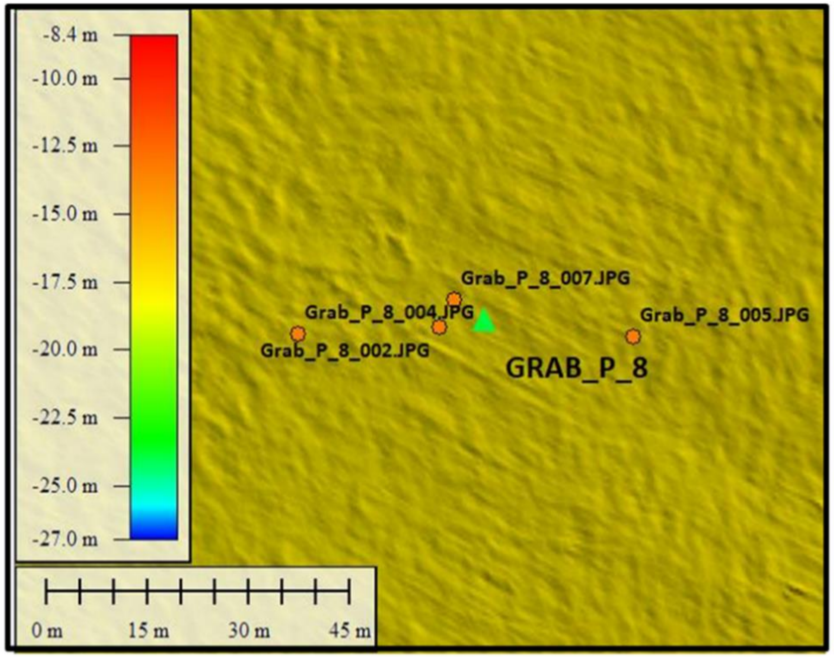
No. of Stills: 6 | Mins of Video: 2 | Track Length: DDV

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Low reflectivity.

Sediment Description
Coarse sand and rare shell debris with irregular ripples

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason).



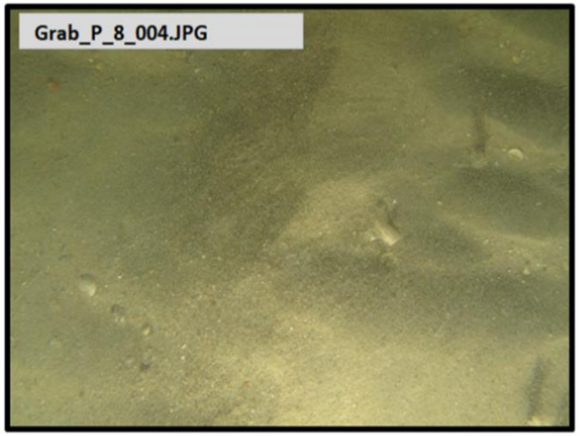


Photo Position: 719076 mE, 5947050 mN

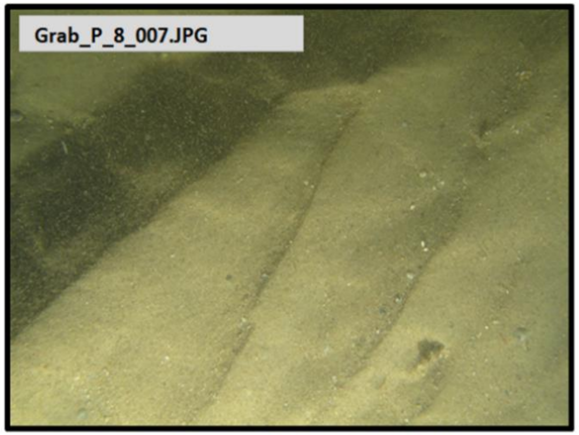


Photo Position: 719099 mE, 5947055 mN

Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_P_09

Survey Area: N5a Pipeline

No. of Stills: 6 **Mins of Video: 1** **Track Length: DDV**

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Variable reflectivity with scars in seabed.

Sediment Description
Coarse sand and rare shell debris with irregular ripples

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Corystes cassivelaunus* (Masked crab). **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** Actinopterygii sp.

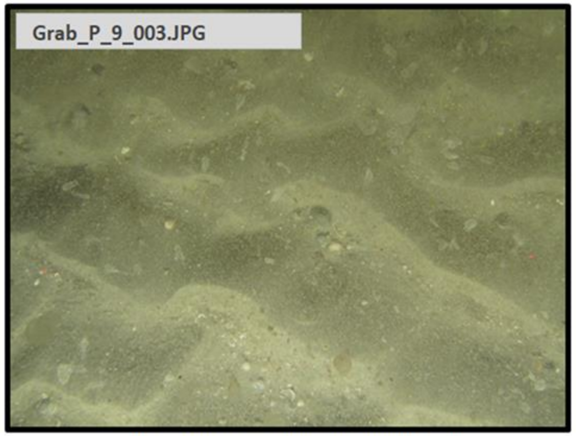


Photo Position: 718861 mE, 5945912 mN

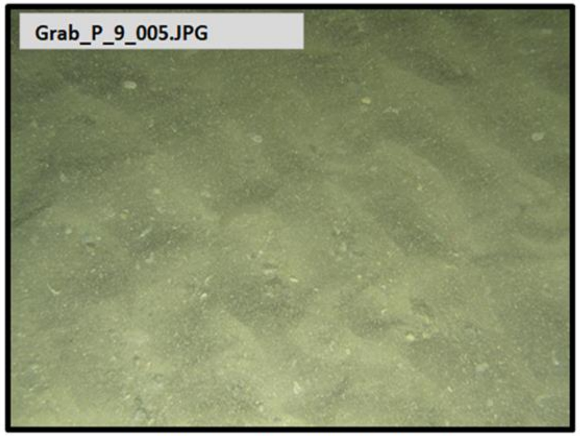


Photo Position: 718862 mE, 5945911 mN

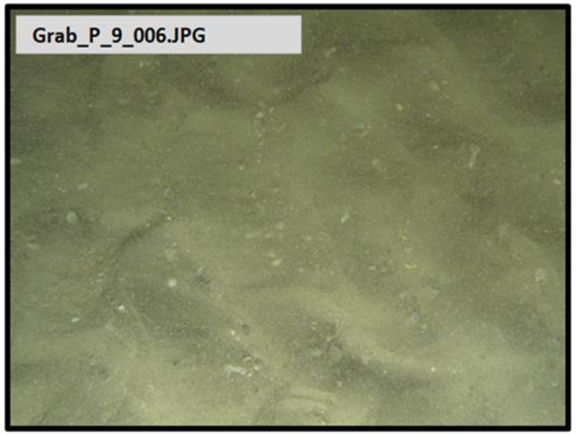


Photo Position: 718863 mE, 5945911 mN

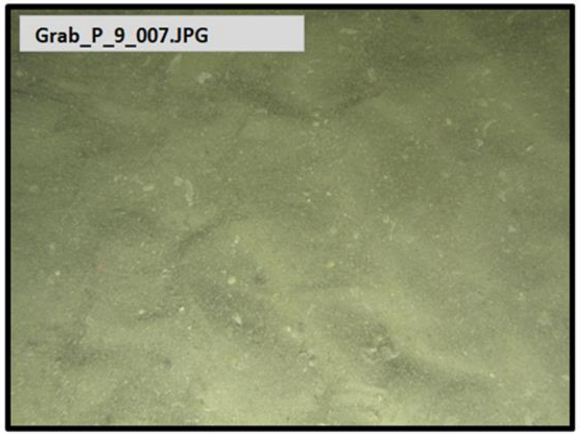
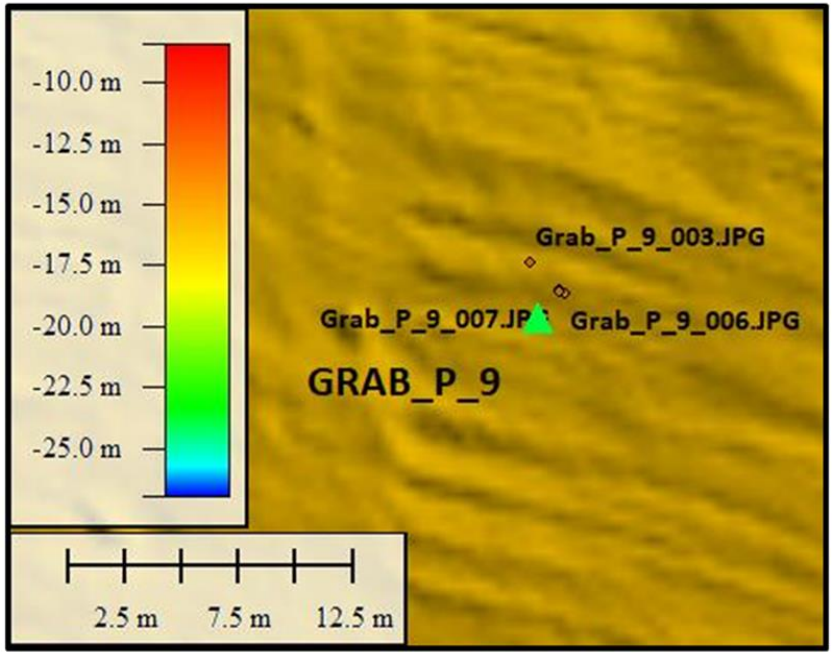


Photo Position: 718862 mE, 5945911 mN



Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Grab_P_10_003.JPG

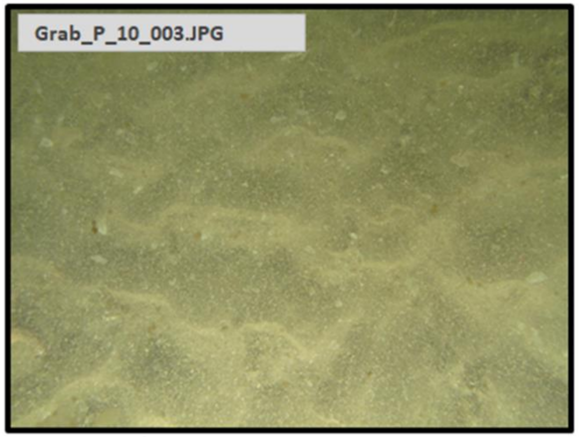


Photo Position: 718778 mE, 5944917 mN

Habitat Summary Information: Grab_P_010

Survey Area: N5a Pipeline

No. of Stills: 8 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Area of variable reflectivity.

Sediment Description
Coarse sand.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** *Asterias rubens* (Common starfish).

Grab_P_10_004.JPG

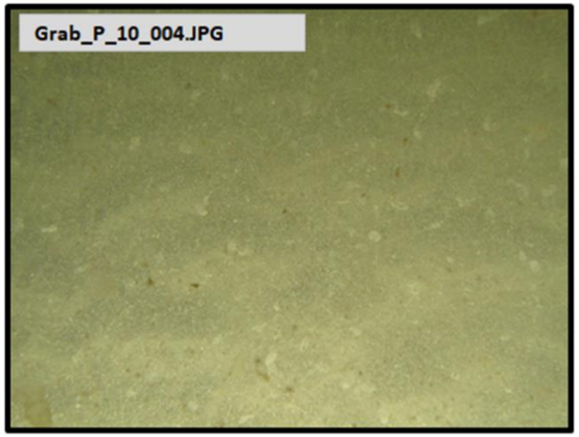


Photo Position: 718778 mE, 5944917 mN

Grab_P_10_006.JPG

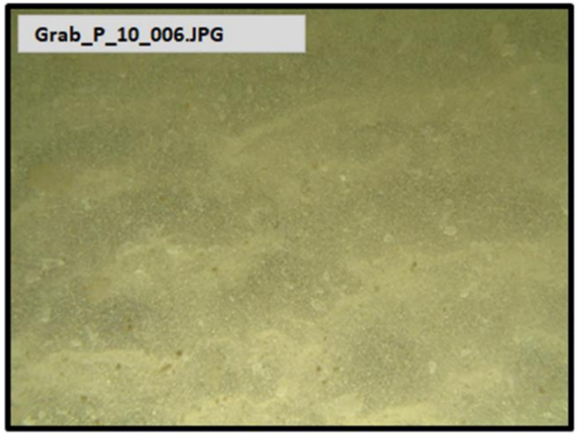
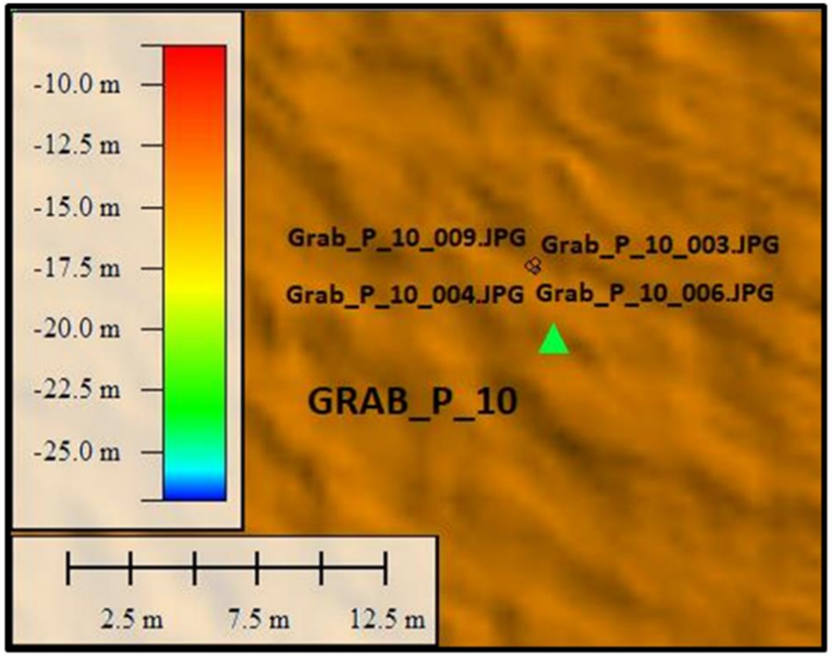


Photo Position: 718778 mE, 5944917 mN



Grab_P_10_009.JPG

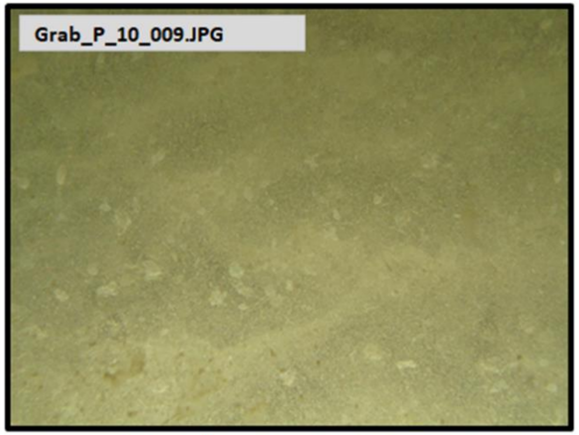


Photo Position: 718778 mE, 5944917 mN

Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_P_011

Survey Area: N5a Pipeline

No. of Stills: 8 | **Mins of Video: 2** | **Track Length: DDVm**

Site Selection Criteria
Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation
Low reflectivity.

Sediment Description
Coarse sand and rare shell debris with irregular ripples.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** Brachyura sp.

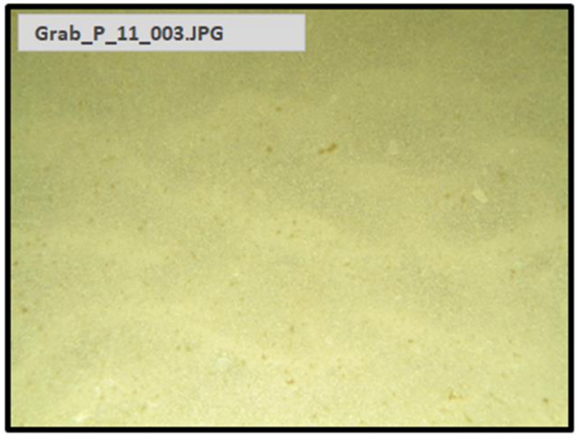


Photo Position: 718696 mE, 5943920 mN

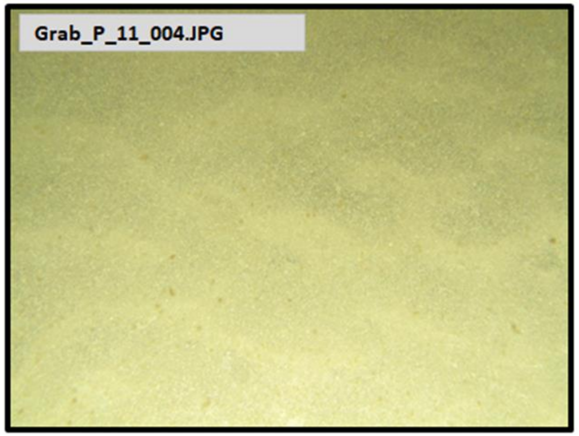


Photo Position: 718696 mE, 5943920 mN

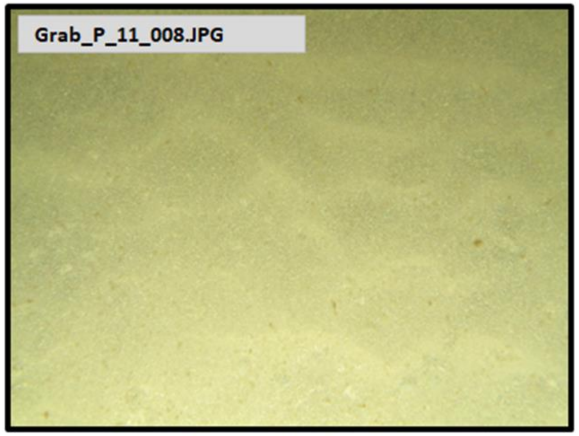


Photo Position: 718697 mE, 5943920 mN

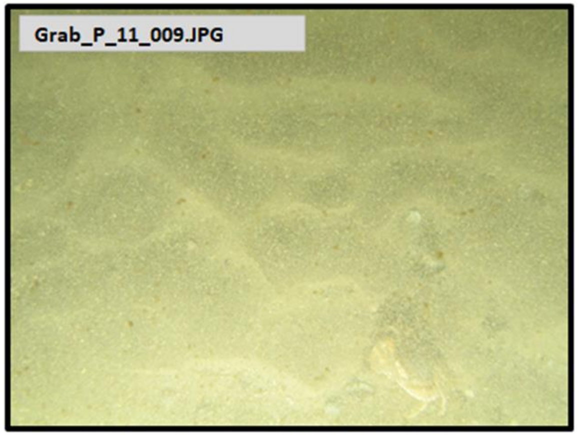
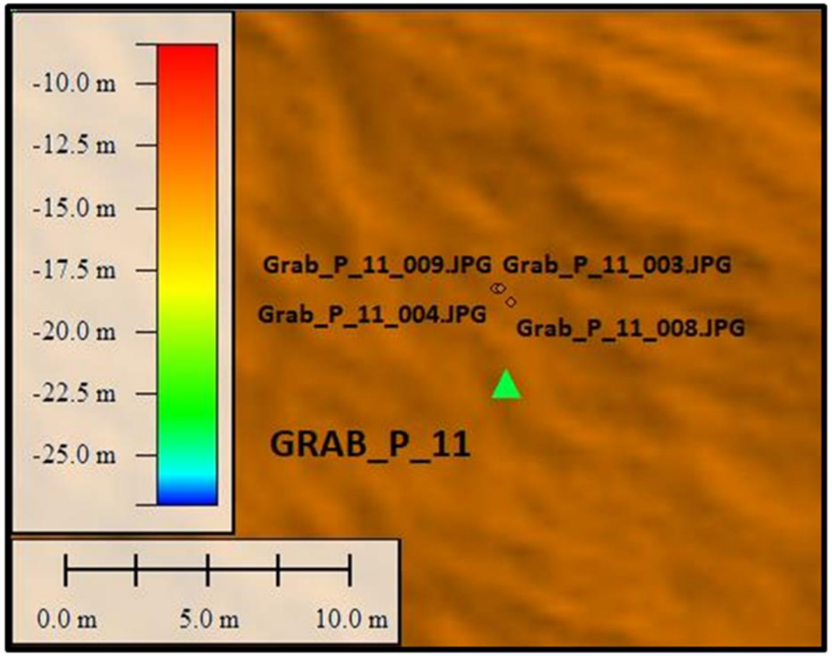


Photo Position: 718697 mE, 5943920 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_P_012

Survey Area: N5a Pipeline

No. of Stills: 8 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Area of variable reflectivity with depressions.

Sediment Description

Coarse sand and rare shell debris with irregular ripples.

Conspicuous Fauna

Cnidaria: Actiniaria sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Liocarcinus depurator* (Sandy swimming crab), Brachyura sp, *Cancer maenus*. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** *Callionymus lyra* (Common dragonet), Gobiidae sp.

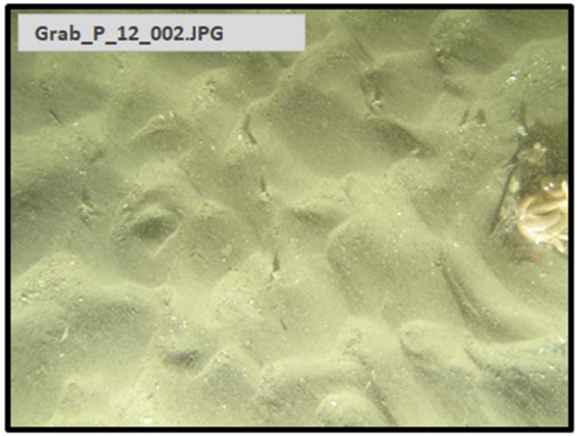


Photo Position: 718613 mE, 5942924 mN

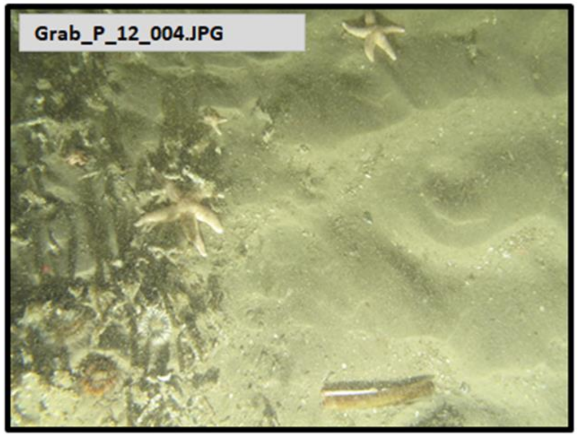


Photo Position: 718614 mE, 5942924 mN

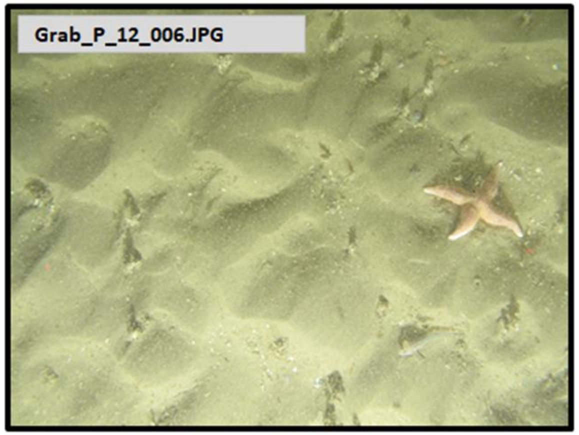


Photo Position: 718614 mE, 5942923 mN

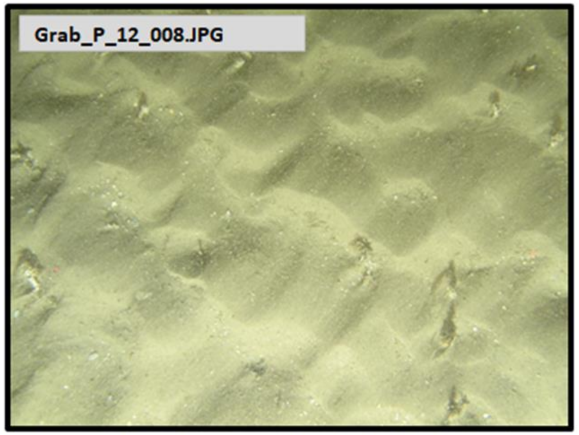
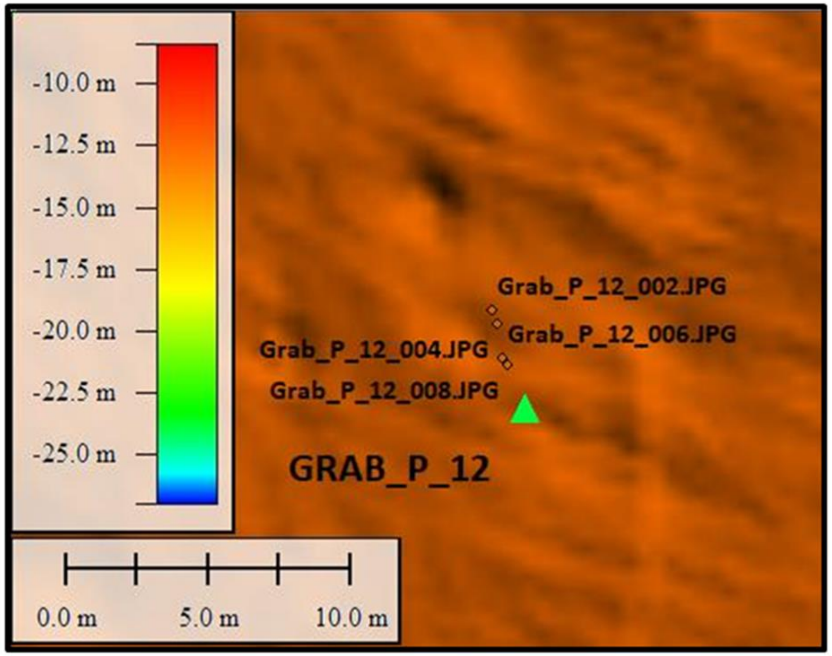
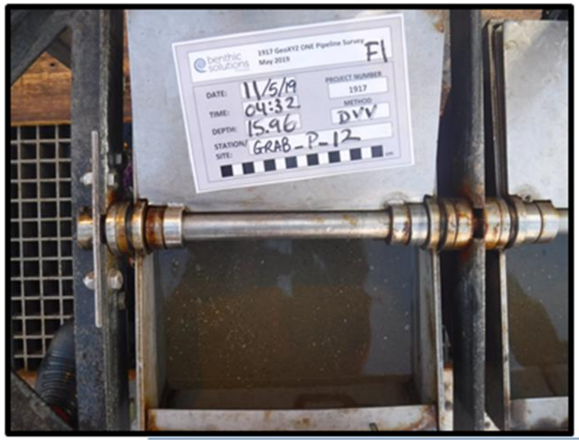


Photo Position: 718614 mE, 5942922 mN





Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

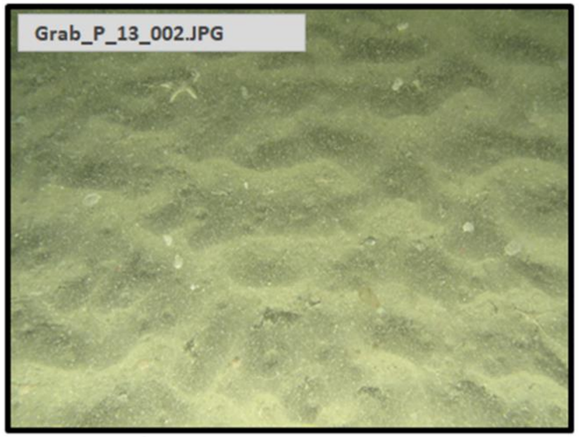


Photo Position: 718531 mE, 5941926 mN

Habitat Summary Information: Grab_P_013

Survey Area: N5a Pipeline

No. of Stills: 7 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Area of low reflectivity with some potential scarring.

Sediment Description

Coarse sand with irregular ripples.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** *Asterias rubens* (Common starfish), Ophiurida sp.

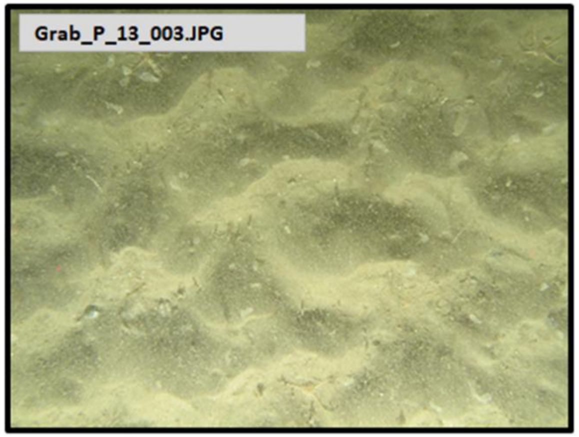


Photo Position: 718531 mE, 5941926 mN

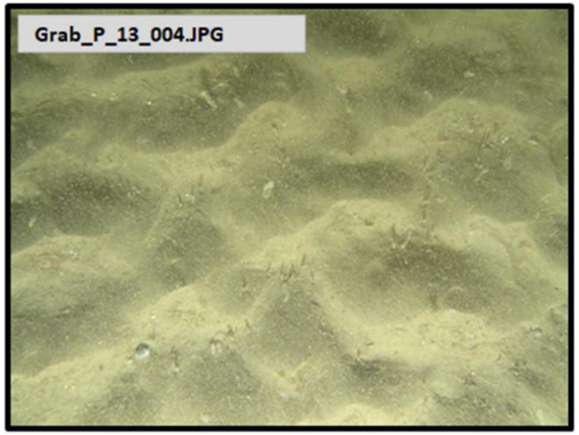
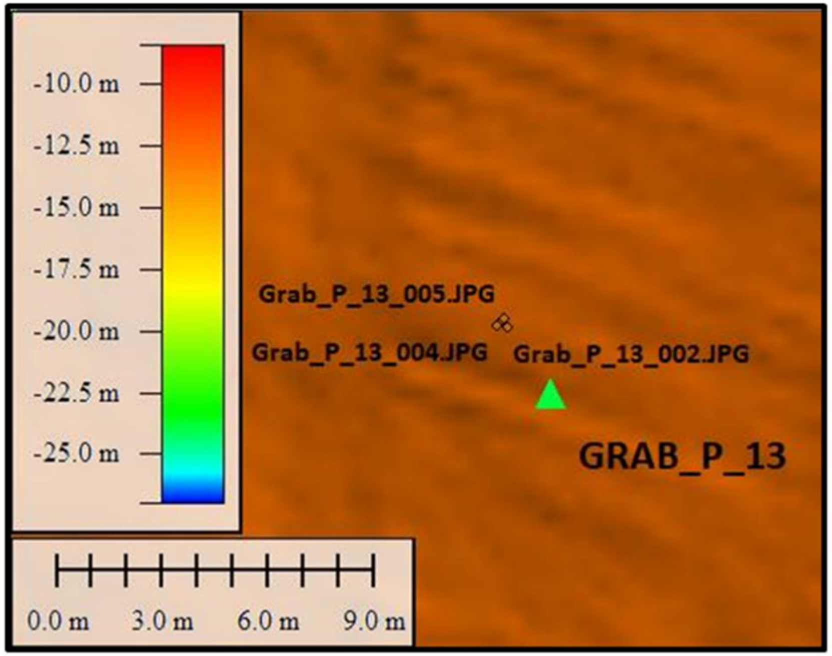


Photo Position: 718531 mE, 5941926 mN



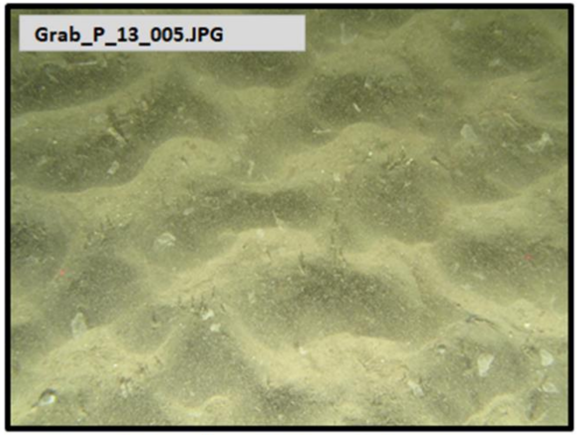
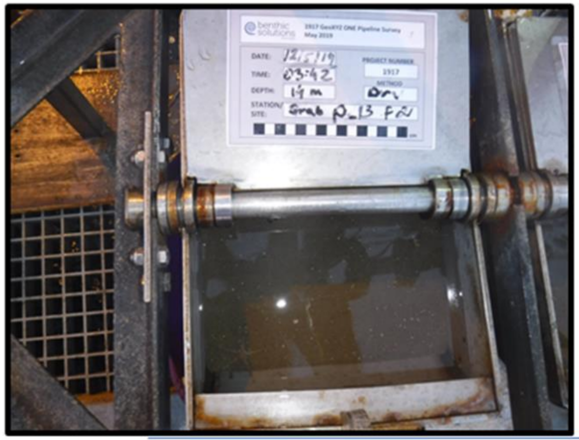


Photo Position: 718531 mE, 5941926 mN



Sediment Example Image

Grab Location Camera Track Selected Underwater Still

Sieved Sample Image

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

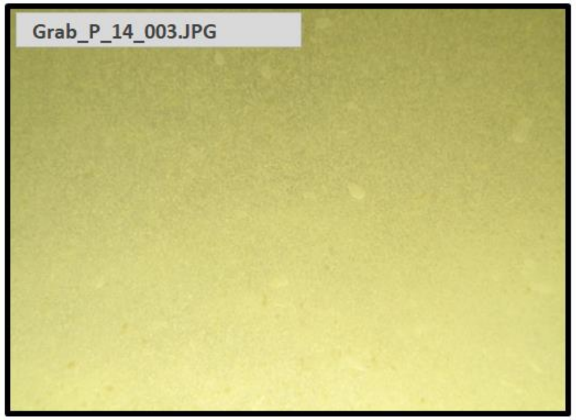


Photo Position: 718449 mE, 5940928 mN

Habitat Summary Information: Grab_P_014

Survey Area: N5a Pipeline

No. of Stills: 5 **Mins of Video: 1** **Track Length: DDV**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity

Sediment Description

No visiblity

Conspicuous Fauna

No visibility

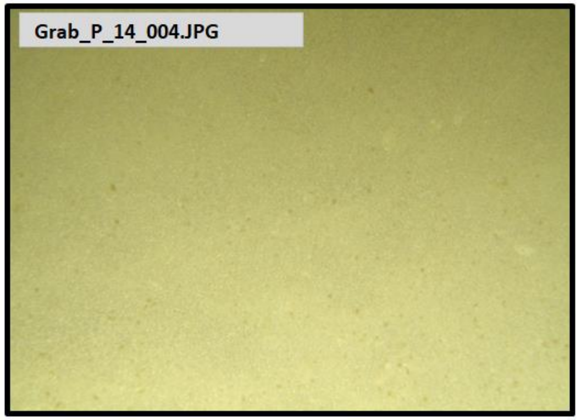


Photo Position: 718451 mE, 5940927 mN

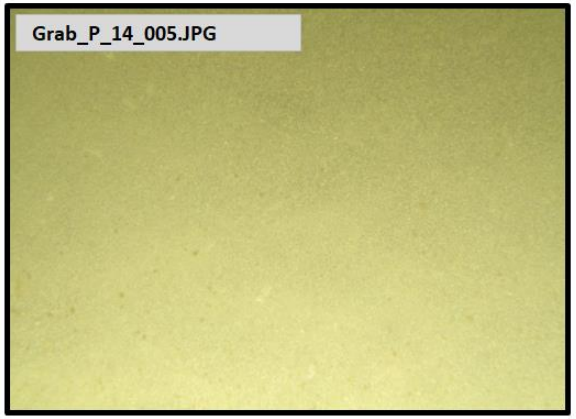
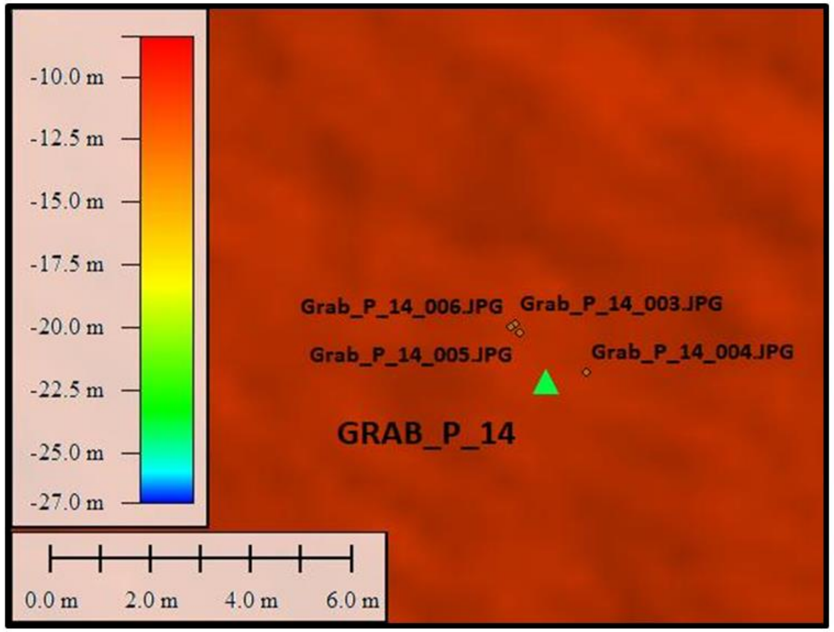


Photo Position: 718450 mE, 5940928 mN



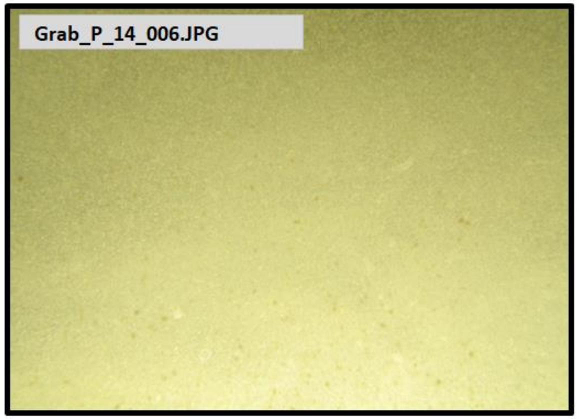
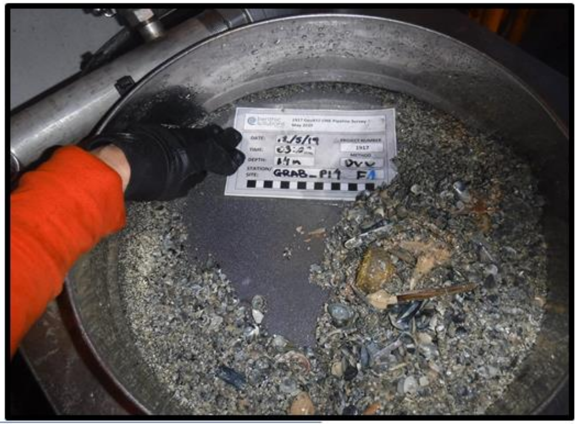


Photo Position: 718449 mE, 5940928 mN

Sediment Example Image



Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_P_015

Survey Area: N5a Pipeline

No. of Stills: 5 **Mins of Video: 2** **Track Length: DDV**

Site Selection Criteria

Pipeline Route - Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity.

Sediment Description

Coarse sand with irregular ripples.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Chordata:** Actinopterygii sp.

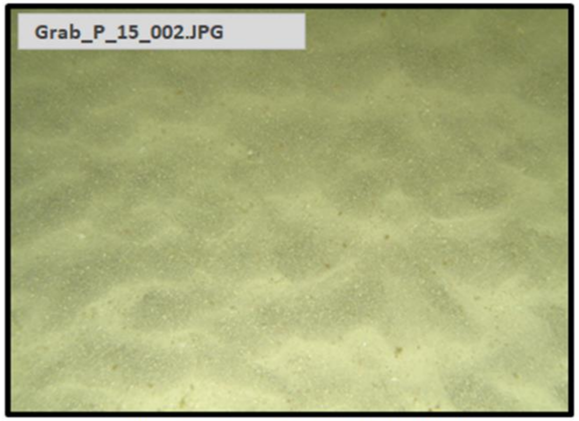


Photo Position: 718366 mE, 5939934 mN

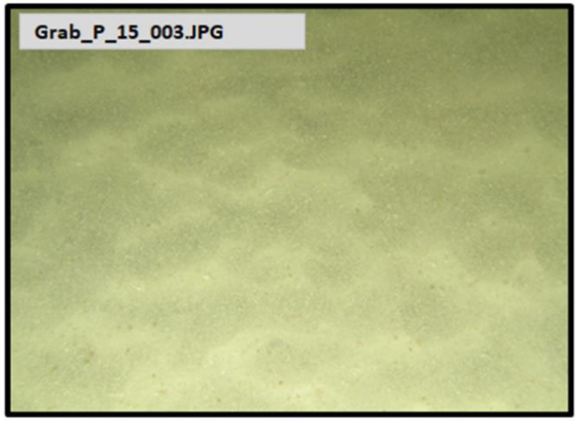


Photo Position: 718366 mE, 5939934 mN

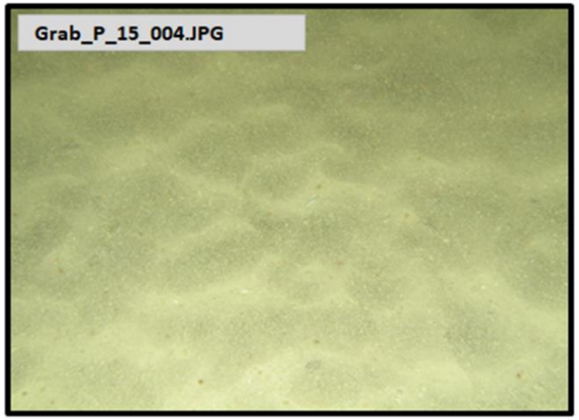


Photo Position: 718366 mE, 5939934 mN

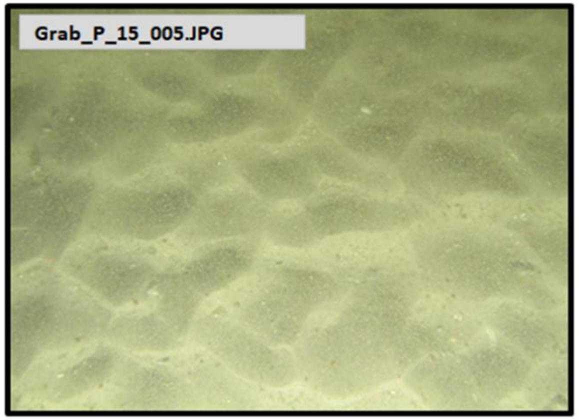
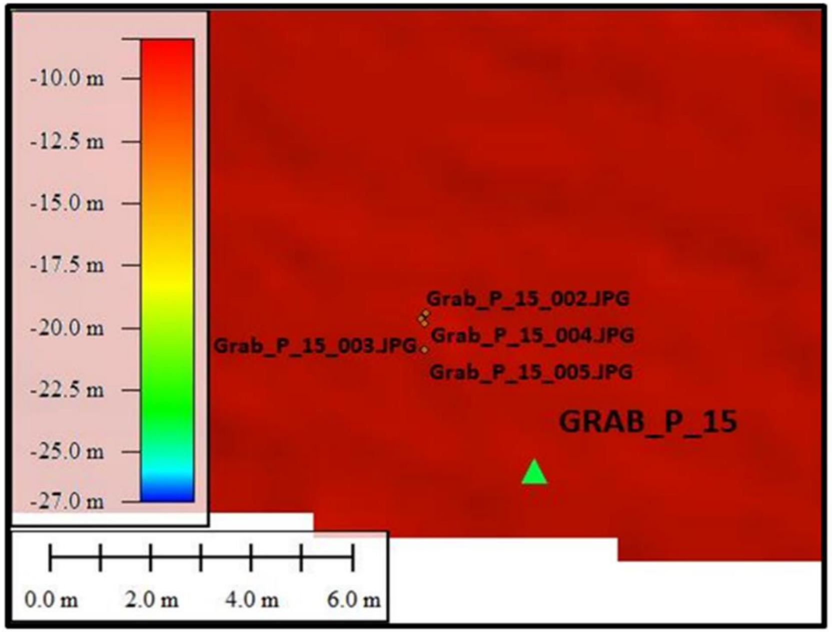


Photo Position: 718366 mE, 5939933 mN



Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C_0

Survey Area: N5a Cable Route

Site Selection Criteria

Original Cable Route and N5a well centre location. Covered using transect N5a_1 and N5a_2.

Analogue Interpretation

Low reflectivity.

Sediment Description

Slightly gravelly/shelly coarse sand.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** *Asterias rubens* (Common starfish).

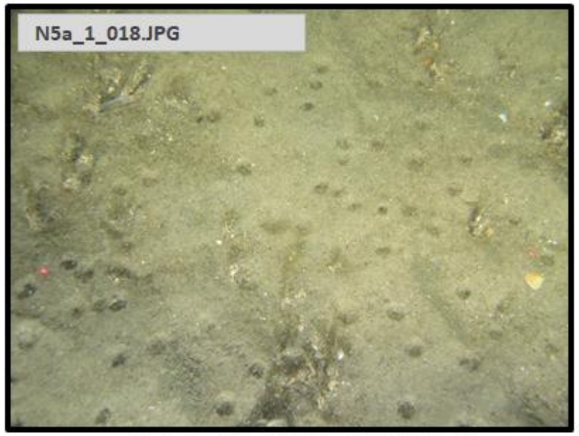


Photo Position: 721606 mE, 5954649 mN

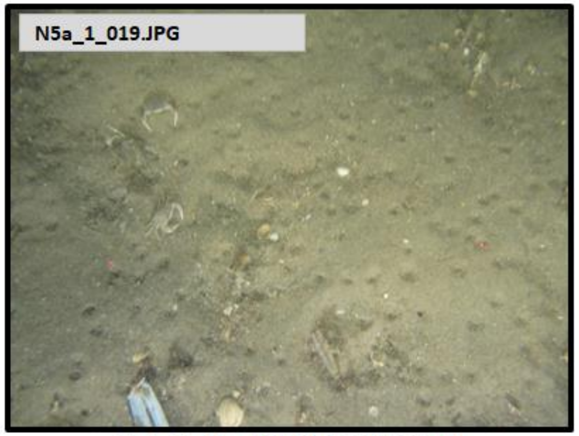


Photo Position: 721607 mE, 5954652 mN

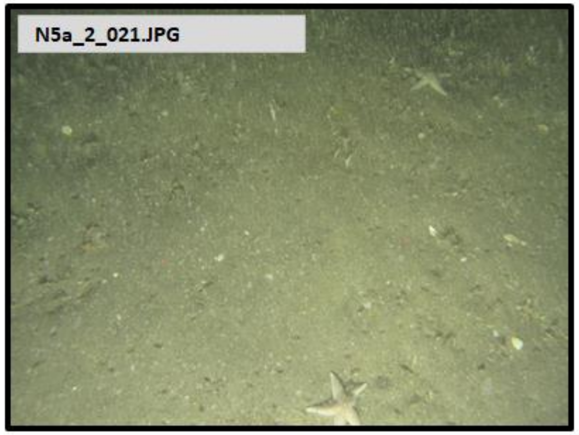


Photo Position: 721610 mE, 5954650 mN

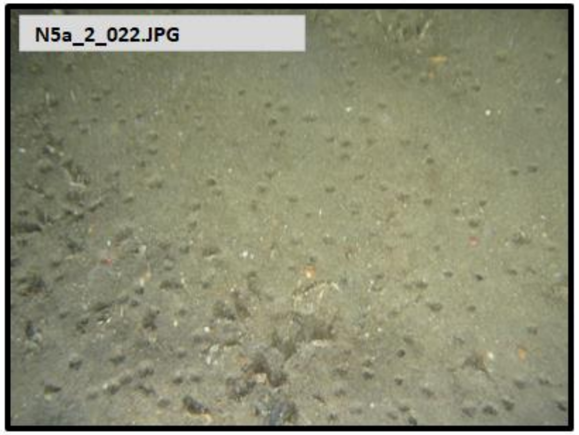
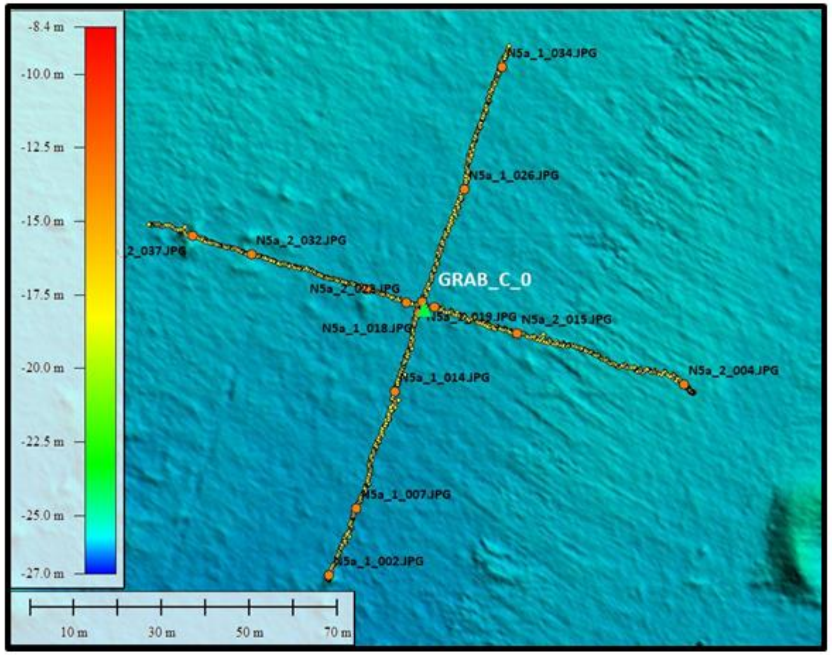


Photo Position: 721603 mE, 5954651 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C_01

Survey Area: N5a Cable Route

No. of Stills: 2 | Mins of Video: 1 | Track Length: DDV

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

Area of variable high reflectivity with raised area near Grab location.

Sediment Description

Coarse sand littered with shell fragments.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** Decapoda sp, *Liocarcinus* sp. **Echinodermata:** *Asterias rubens* (Common starfish).

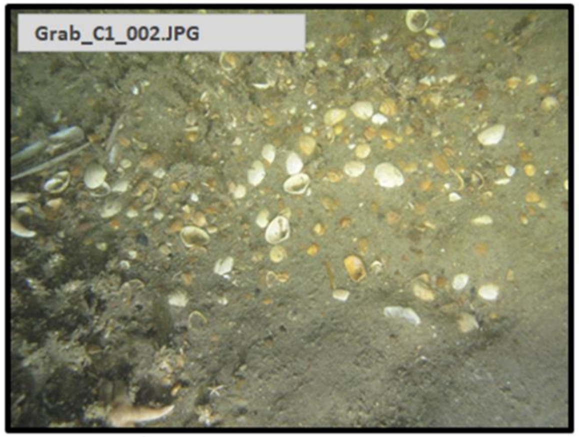


Photo Position: 722598 mE, 5954539 mN

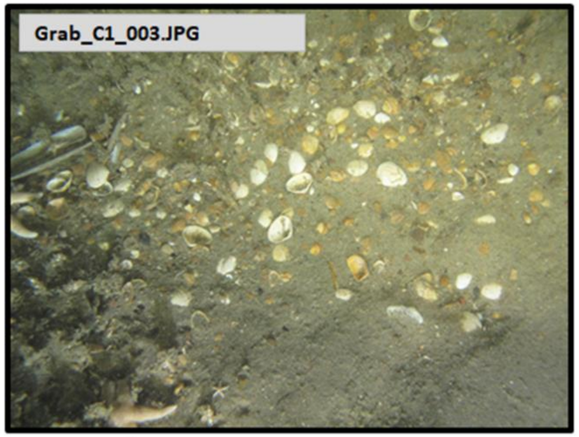


Photo Position: 722598 mE, 5954539 mN

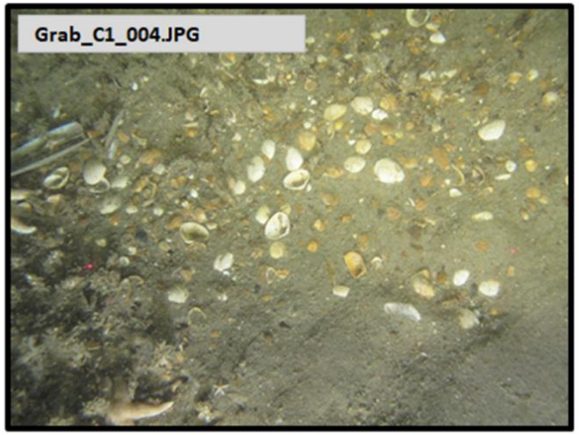


Photo Position: 0 mE, 0 mN

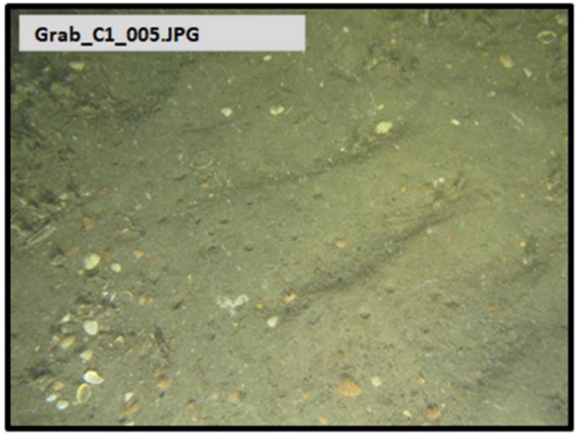
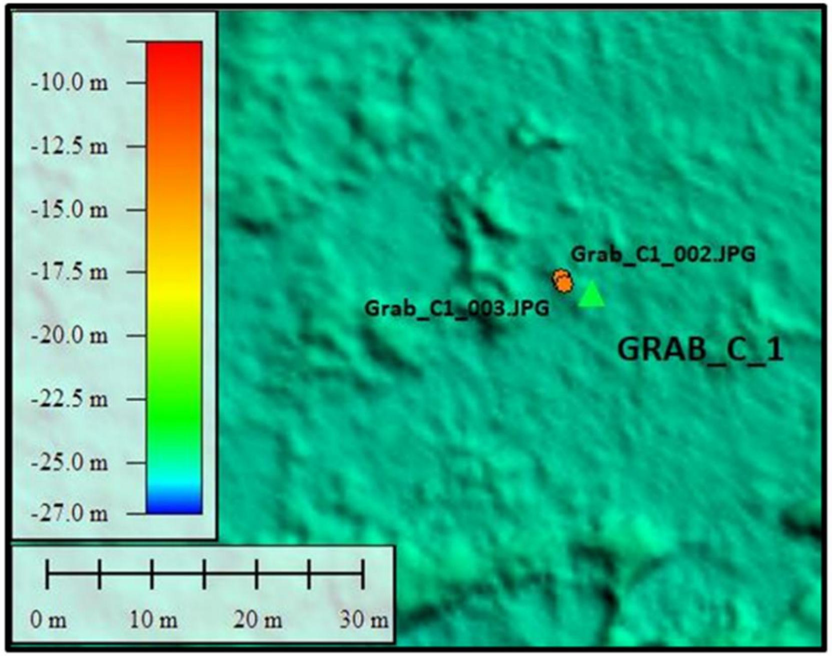


Photo Position: 0 mE, 0 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_C_02

Survey Area: N5a Cable Route

No. of Stills: 5 **Mins of Video: 1** **Track Length: DDV**

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

Area of variable reflectivity.

Sediment Description

Coarse sand.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Liocarcinus* sp. **Mollusca:** *Loligo vulgaris* . **Echinodermata:** *Asterias rubens* (Common starfish).

Grab_C2_002.JPG

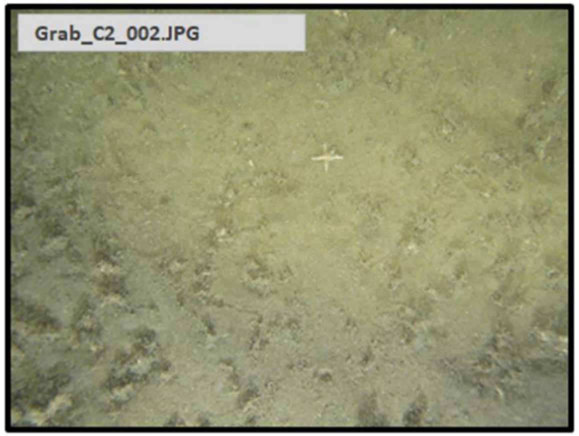


Photo Position: 723594 mE, 5954423 mN

Grab_C2_004.JPG

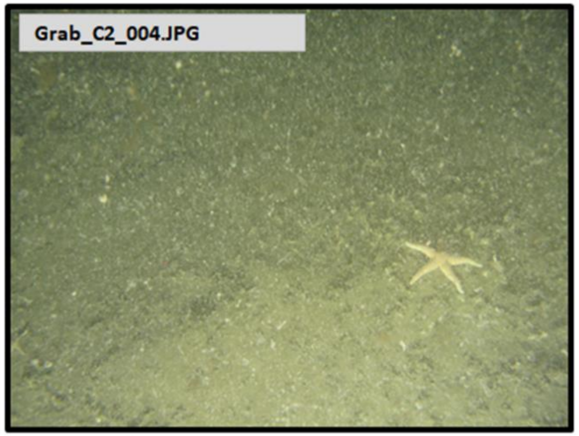


Photo Position: 723594 mE, 5954423 mN

Grab_C2_005.JPG

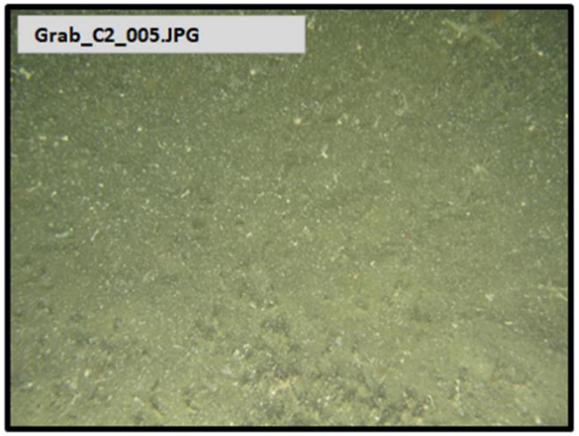


Photo Position: 723596 mE, 5954422 mN

Grab_C2_006.JPG

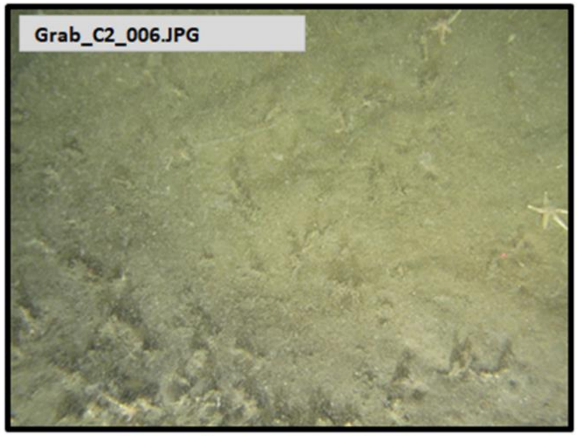
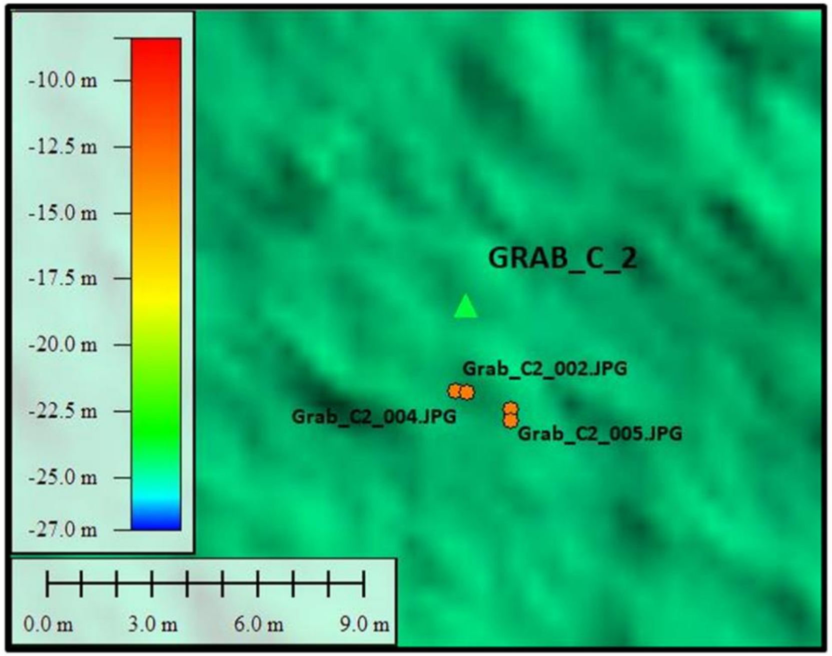


Photo Position: 723596 mE, 5954422 mN



Sediment Example Image

Sieved Sample Image

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C_03

Survey Area: N5a Cable Route

No. of Stills: 8 **Mins of Video: 3** **Track Length: DDV**

Site Selection Criteria
Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation
Low reflectivity.

Sediment Description
Coarse sand ripples with small shell fragments.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Liocarcinus* sp. **Echinodermata:** *Asterias rubens* (Common starfish).

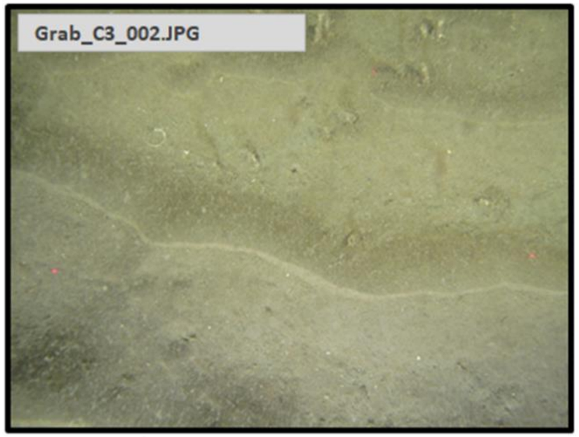


Photo Position: 724589 mE, 5954311 mN

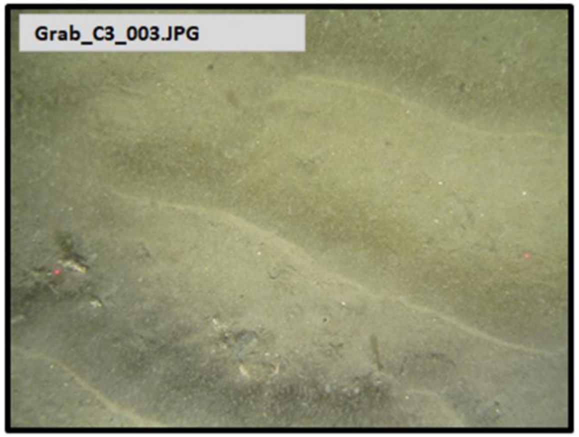


Photo Position: 724589 mE, 5954311 mN

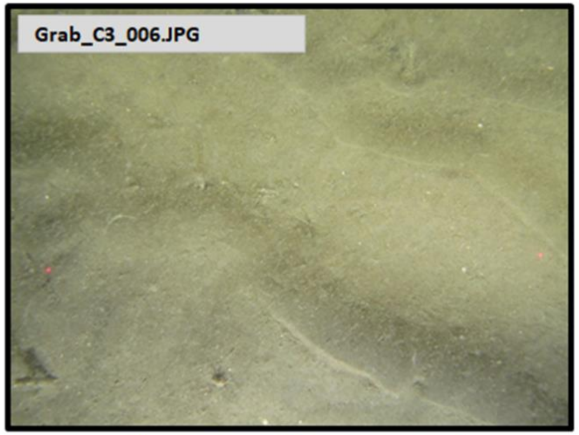
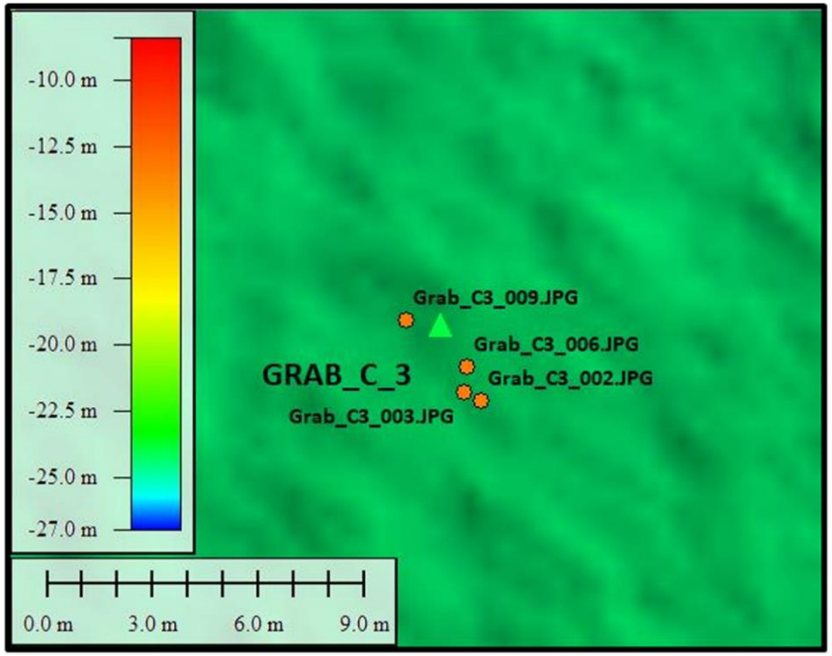


Photo Position: 724589 mE, 5954312 mN



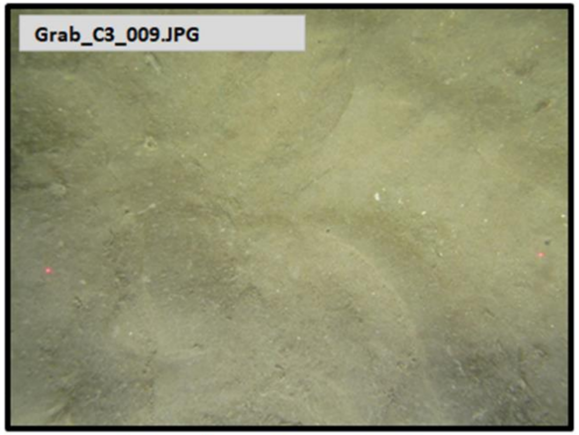


Photo Position: 724587 mE, 5954313 mN

Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C_04

Survey Area: N5a Cable Route

No. of Stills: 9 | Mins of Video: 3 | Track Length: DDV

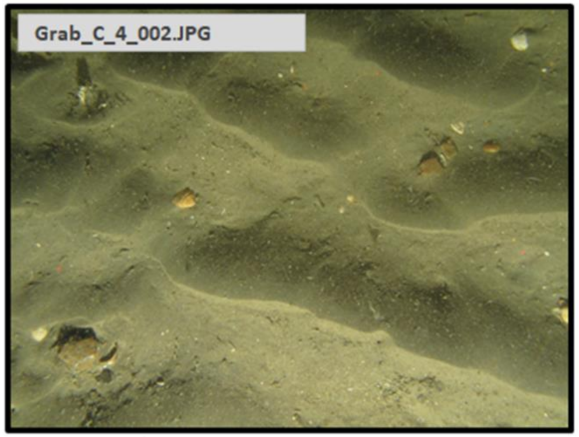


Photo Position: 725582 mE, 5954199 mN

Photo Position: 725583 mE, 5954200 mN

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity.

Sediment Description

Coarse sand ripples with small shell fragments.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** Decapoda sp. **Echinodermata:** *Asterias rubens* (Common starfish).

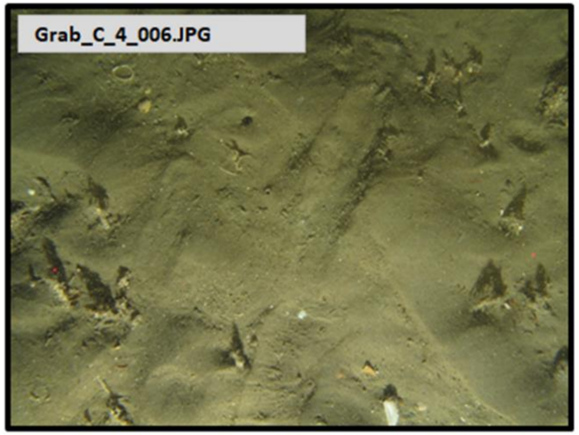
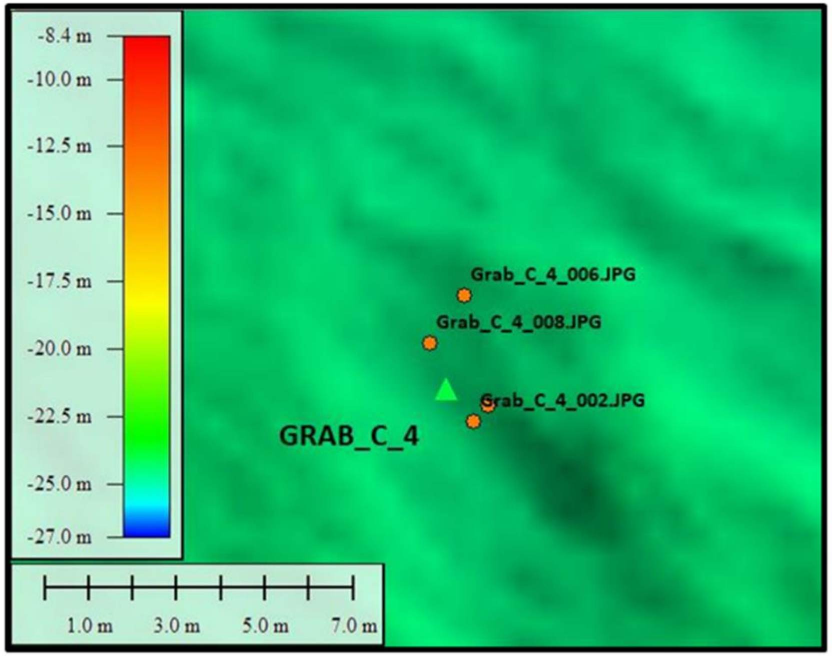


Photo Position: 725582 mE, 5954202 mN



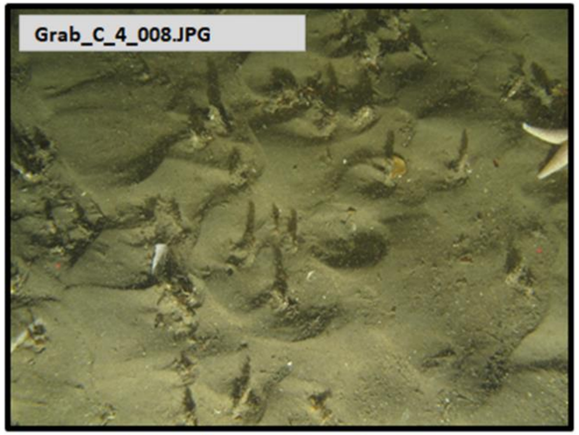


Photo Position: 725581 mE, 5954201 mN

Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_C_05

Survey Area: N5a Cable Route

No. of Stills: 9 | Mins of Video: 3 | Track Length: DDV

Site Selection Criteria
Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation
Low reflectivity.

Sediment Description
Coarse sand ripples with small shell fragments.

Conspicuous Fauna
Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** *Liocarcinus* sp. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** possibly *Callionymus lyra* (Common dragonet).

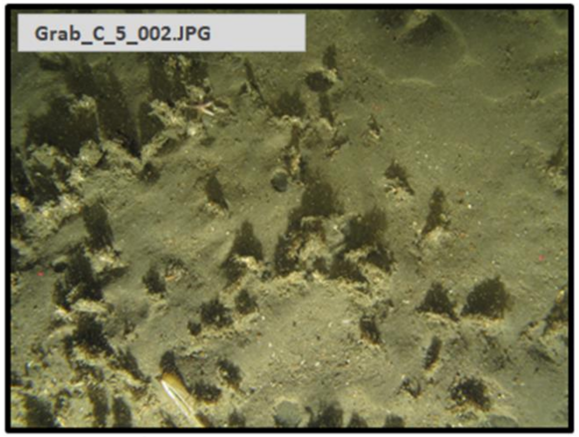


Photo Position: 726576 mE, 5954087 mN

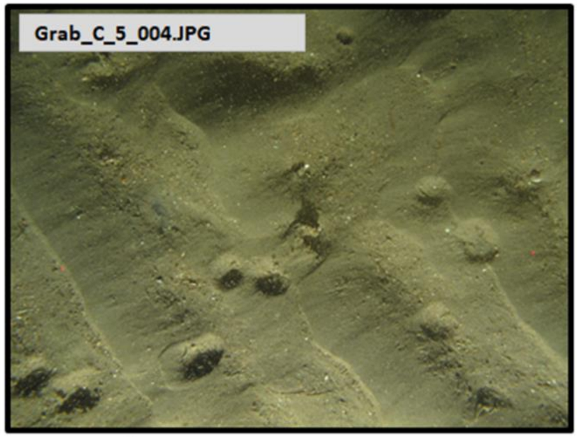


Photo Position: 726578 mE, 5954083 mN

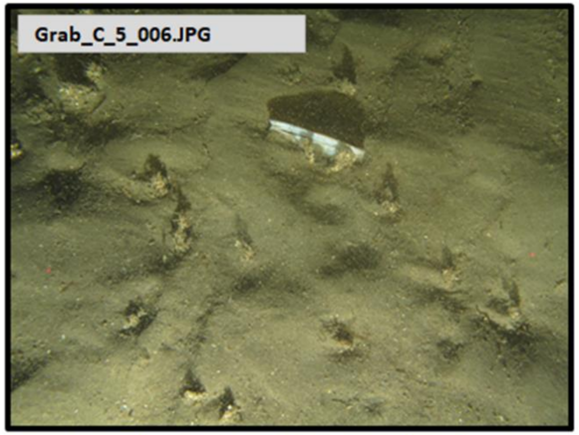


Photo Position: 726575 mE, 5954088 mN

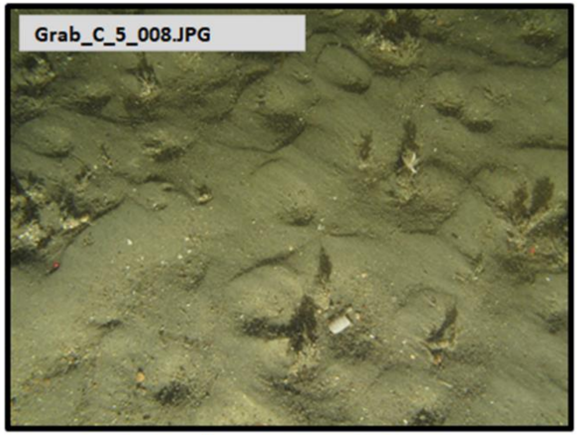
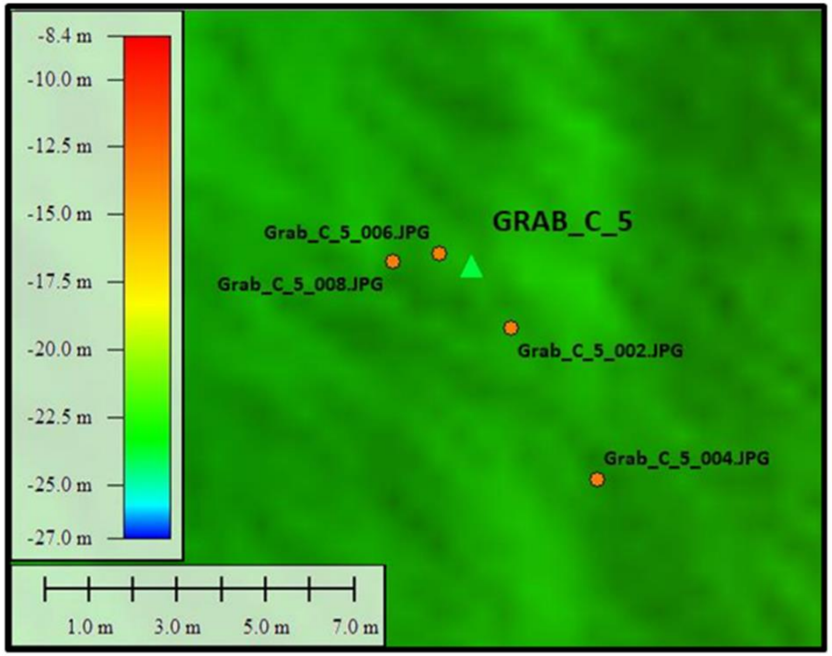


Photo Position: 726574 mE, 5954088 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_C_06

Survey Area: N5a Cable Route

No. of Stills: 4 | Mins of Video: 1 | Track Length: DDV

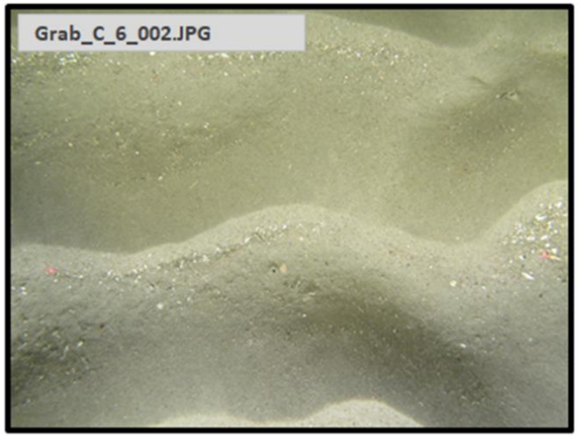


Photo Position: 727352 mE, 5954243 mN

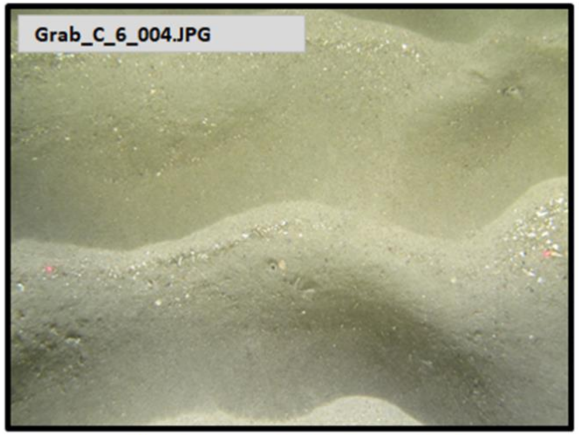


Photo Position: 727352 mE, 5954242 mN

Sediment Example Image

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

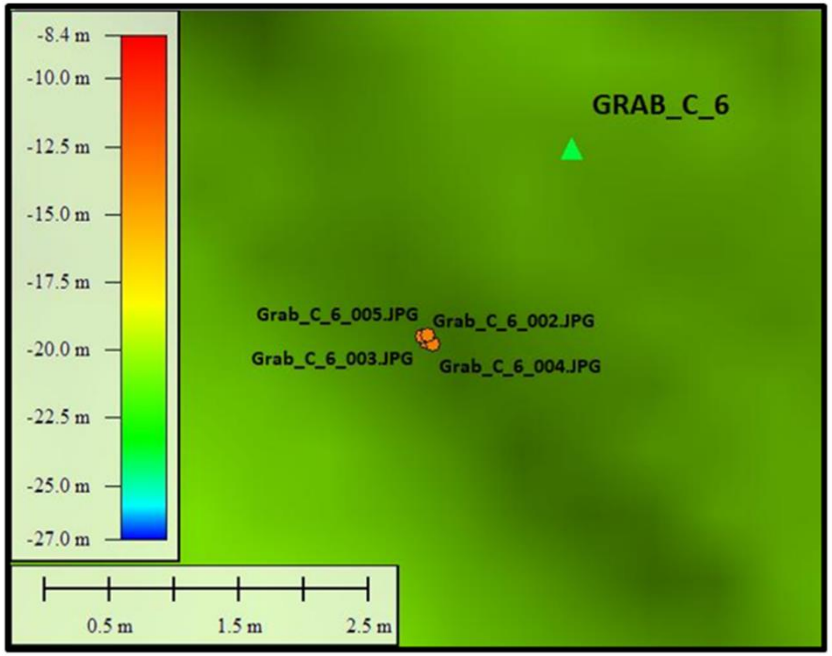
Low reflectivity.

Sediment Description

Coarse sand ripples with small shell fragments that have accumulated within each sand furrow.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason).



Grab Location | Camera Track | Selected Underwater Still

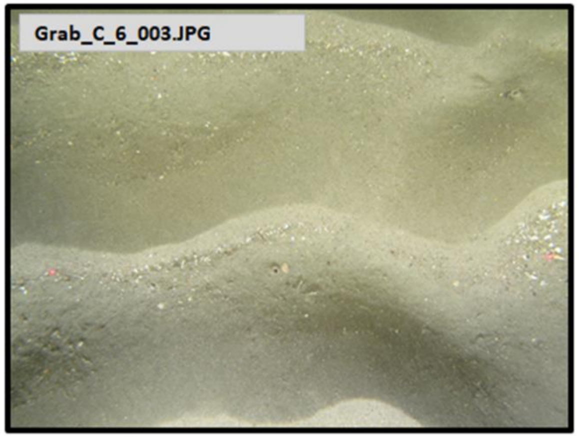


Photo Position: 727352 mE, 5954243 mN

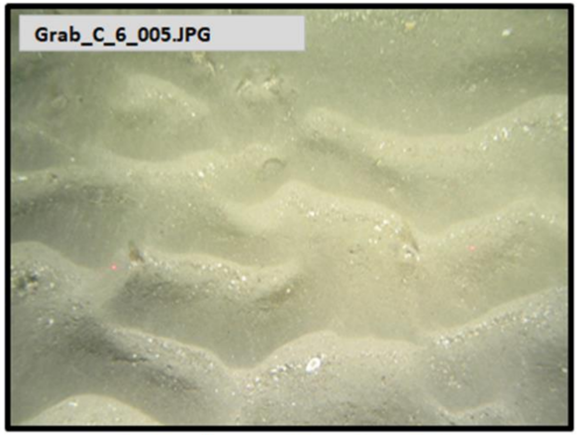


Photo Position: 727352 mE, 5954243 mN


Sieved Sample Image

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_C_07

Survey Area: N5a Cable Route

No. of Stills: 5 | Mins of Video: 1 | Track Length: DDV

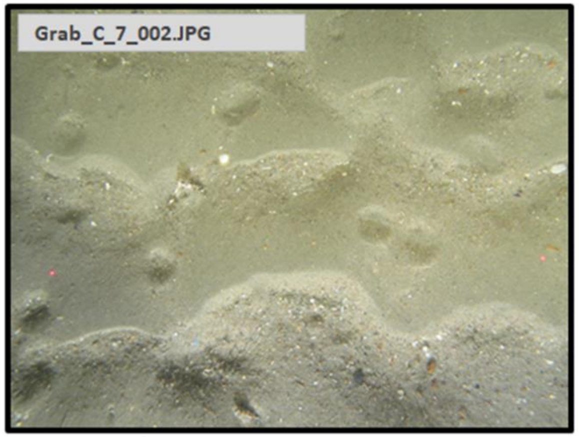


Photo Position: 728147 mE, 5954477 mN

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity.

Sediment Description

Coarse sand ripples with small shell fragments that have accumulated within each sand furrow.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** *Asterias rubens* (Common starfish).

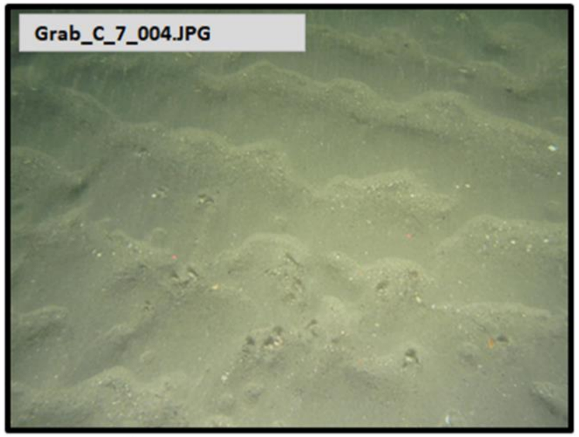


Photo Position: 728147 mE, 5954477 mN

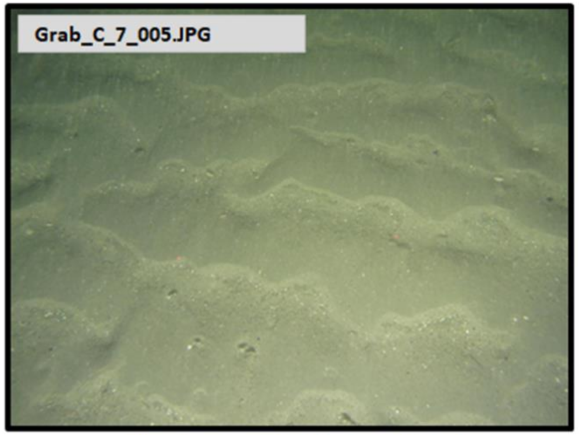
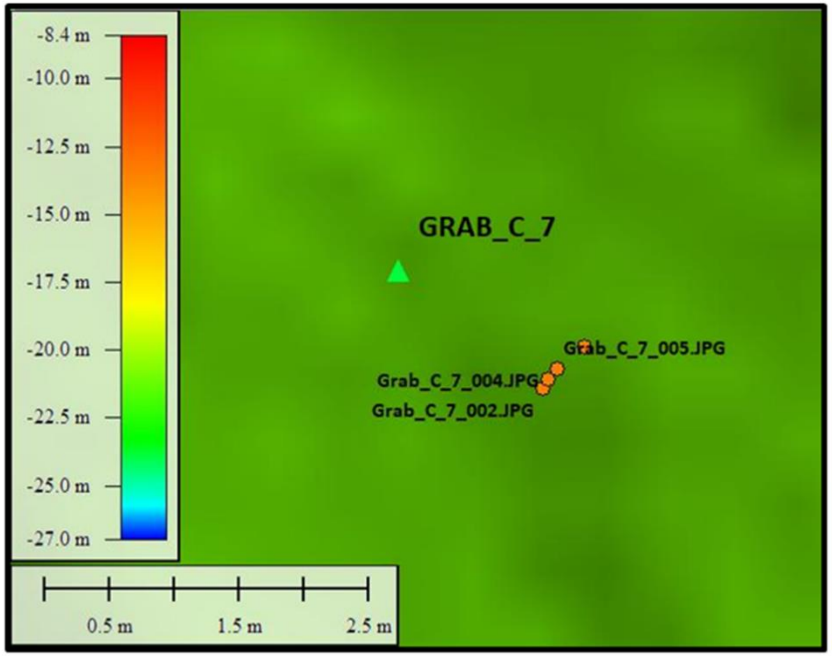


Photo Position: 728147 mE, 5954477 mN



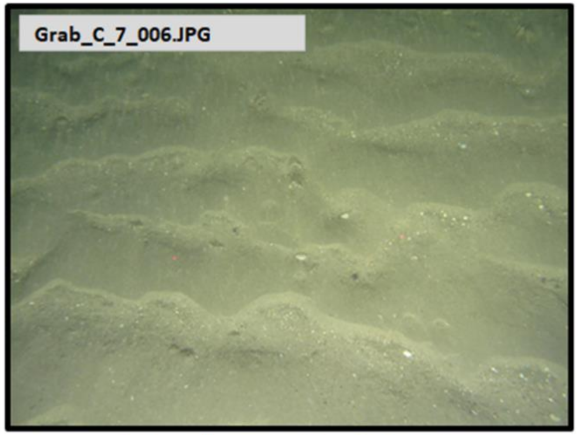
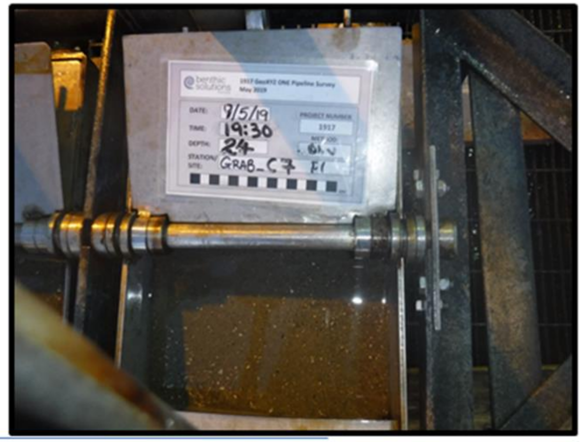


Photo Position: 728148 mE, 5954477 mN

Sediment Example Image



Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: Grab_C_08

Survey Area: N5a Cable Route

No. of Stills: 5 | Mins of Video: 1 | Track Length: DDV

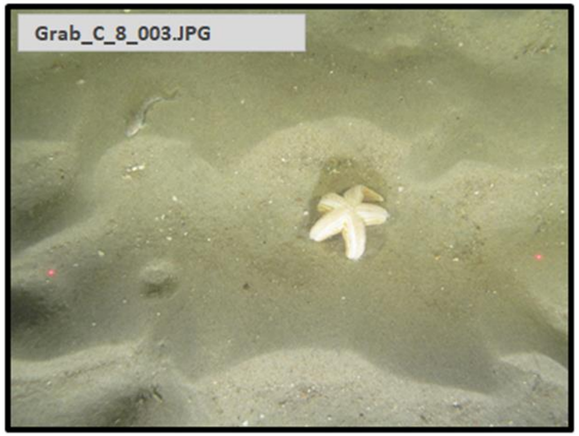


Photo Position: 729107 mE, 5954755 mN

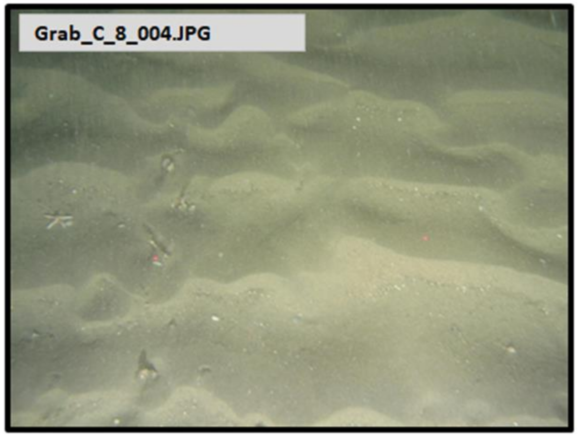


Photo Position: 729107 mE, 5954756 mN

Site Selection Criteria

Original Cable Route – Positioned at 1km intervals.

Analogue Interpretation

Low reflectivity.

Sediment Description

Coarse sand ripples with small shell fragments that have accumulated within each sand furrow.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** Gobiidae sp.

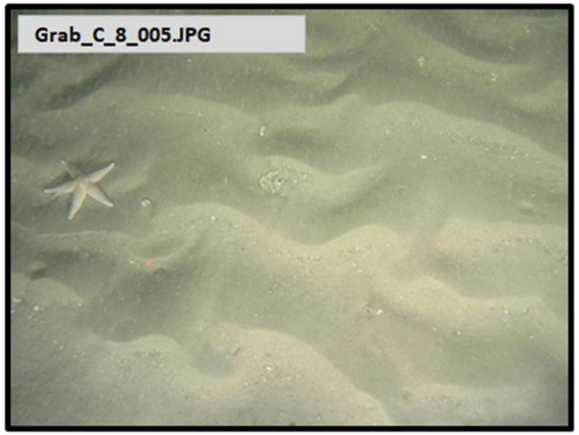


Photo Position: 729108 mE, 5954757 mN

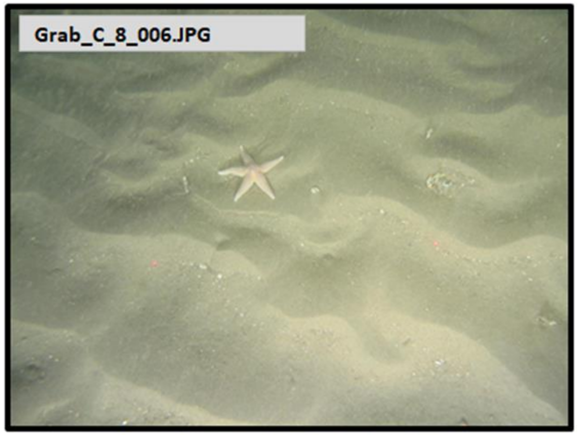
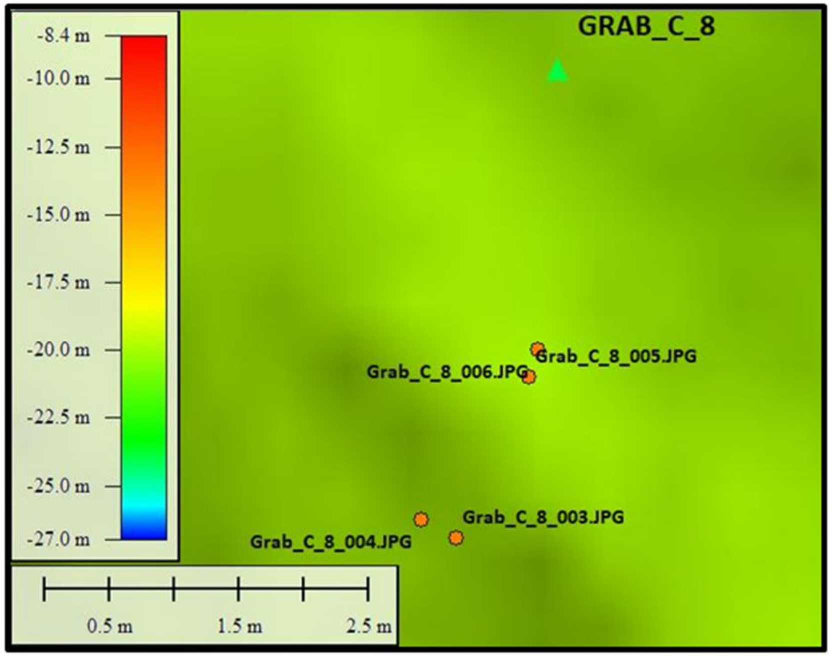


Photo Position: 729108 mE, 5954757 mN



Sediment Example Image

Sieved Sample Image

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

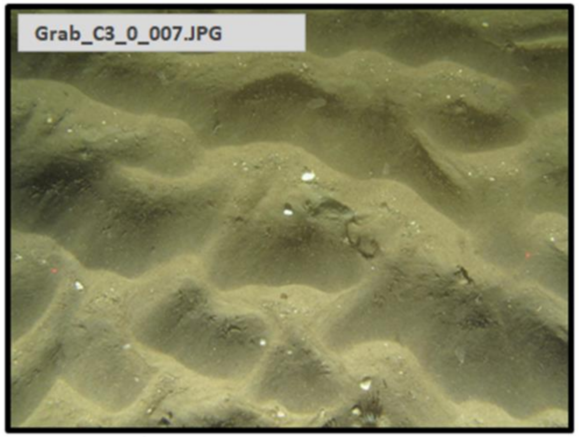


Photo Position: 722245 mE, 5952995 mN

Habitat Summary Information: Grab_C3_0

Survey Area: N5a Cable Route

No. of Stills: 36 Mins of Video: 9 Track Length: 125m

Site Selection Criteria

Secondary Cable Route and N5a second potential well centre location.

Analogue Interpretation

No analogue data.

Sediment Description

Coarse sand ripples with small shell fragments that have accumulated within each sand furrow.

Conspicuous Fauna

Annelida: *Lanice conchilega* (Sand Mason). **Arthropoda:** Decapoda sp., *Corystes cassivelaunus* (Masked crab). **Echinodermata:** *Asterias rubens* (Common starfish), *Ophiura* sp. **Chordata:** Gobiidae sp. , *Ammodytes* sp. (Sand eel).

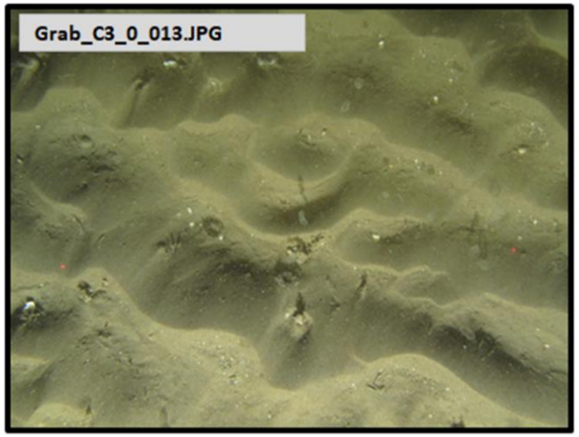


Photo Position: 722260 mE, 5953002 mN

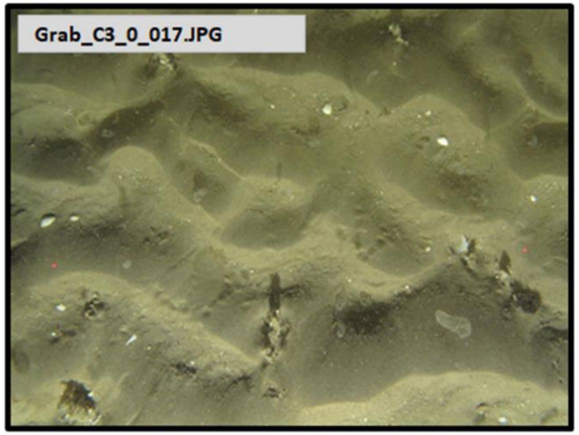
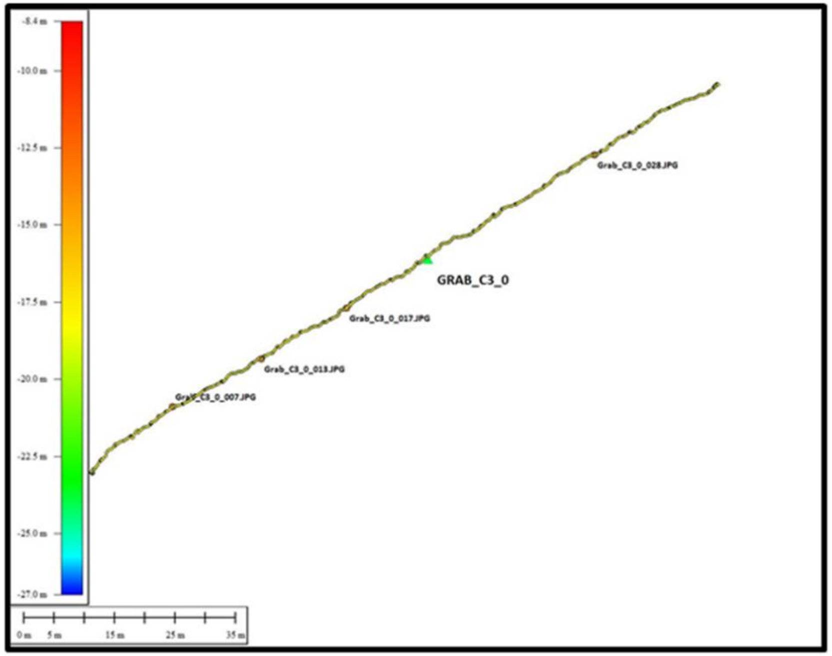


Photo Position: 722274 mE, 5953011 mN



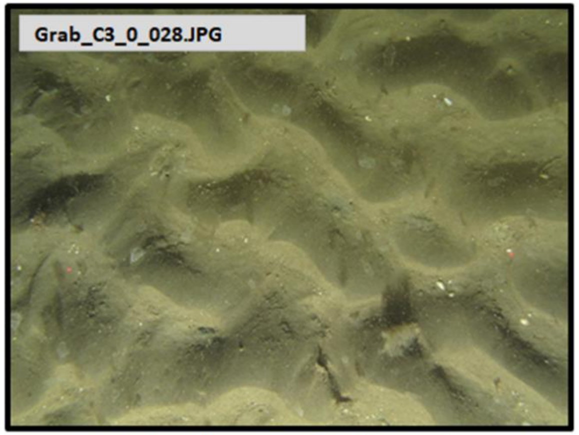


Photo Position: 722315 mE, 5953036 mN

Sediment Example Image

Grab Location Camera Track Selected Underwater Still

Sieved Sample Image

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C3_01

Survey Area: N5a Cable Route

No. of Stills: 7 **Mins of Video: 1** **Track Length: DDV**

Site Selection Criteria
Secondary Cable Route – Positioned to investigate mixed reflectivity sediment.

Analogue Interpretation
No analogue data.

Sediment Description
Coarse shelly sand with partly buried cobbles and slight sand waves.

Conspicuous Fauna
Echinodermata: *Asterias rubens* (Common starfish). **Chordata:** Pleuronectiformes sp.

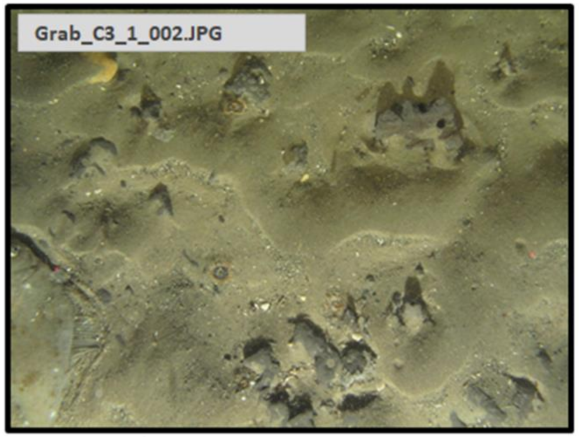


Photo Position: 723807 mE, 5953379 mN

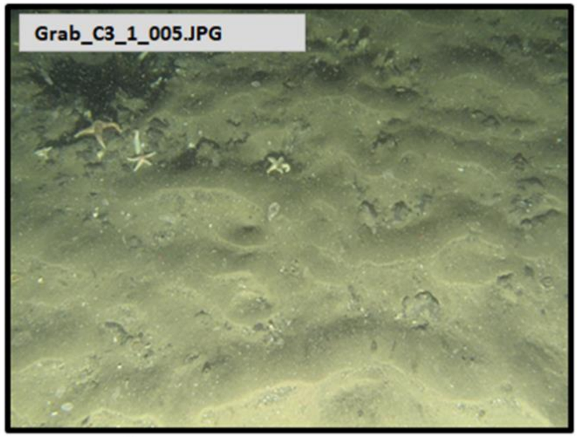


Photo Position: 723807 mE, 5953379 mN

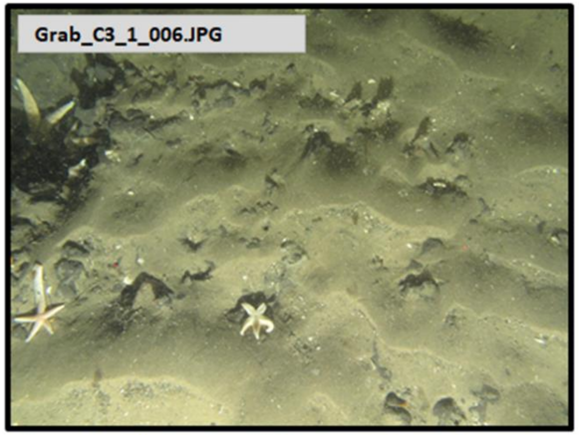


Photo Position: 723808 mE, 5953379 mN

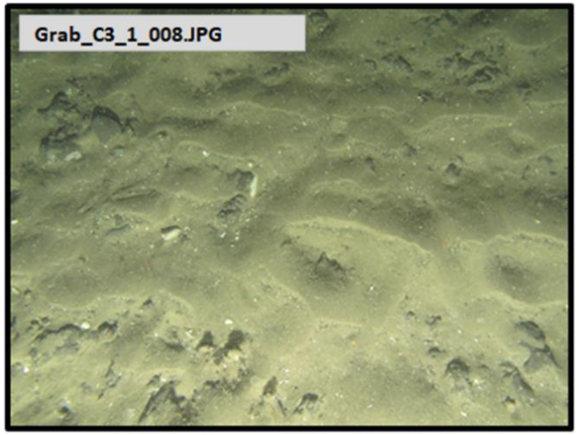
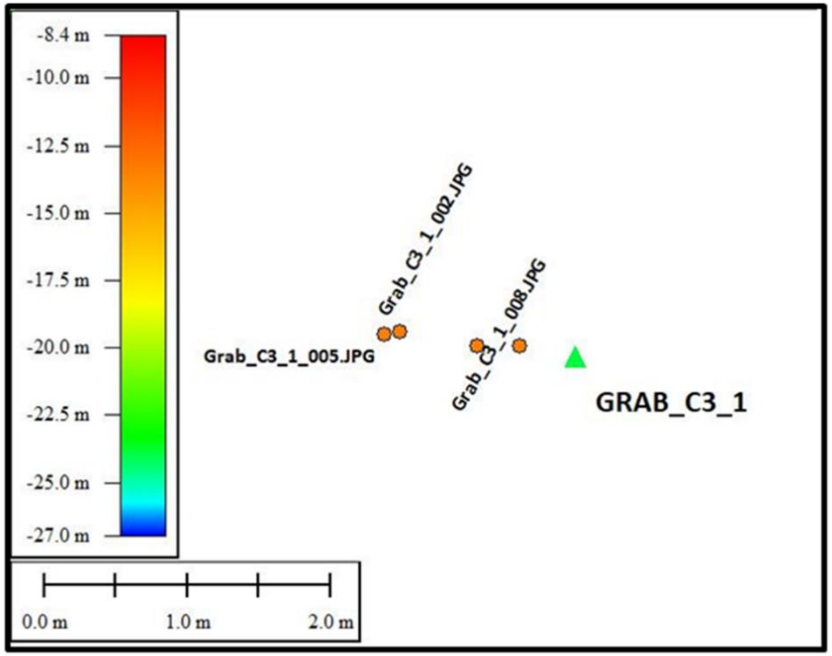


Photo Position: 723808 mE, 5953379 mN




Sediment Example Image


Sieved Sample Image

Grab Location · Camera Track · Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: Grab_C3_02

Survey Area: N5a Cable Route

No. of Stills: 37 | Mins of Video: 13 | Track Length: 180m

Site Selection Criteria

Secondary Cable Route – Positioned to investigate high reflectivity sediment.

Analogue Interpretation

Area of variable reflectivity, scarring on seabed (analogue data only available for half of camera line).

Sediment Description

Gravelly and shelly coarse sand.

Conspicuous Fauna

Cnidaria: *Metridium senile* (Plumose Anemone), Actiniaria sp., Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Cancer pagurus* (Edible crab), Paguridae sp., Decapoda sp., Liocarcinus sp. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** possibly *Callionymus lyra* (Common dragonet), *Ammodytes* sp. (Sand eel), Pleuronectiformes sp.

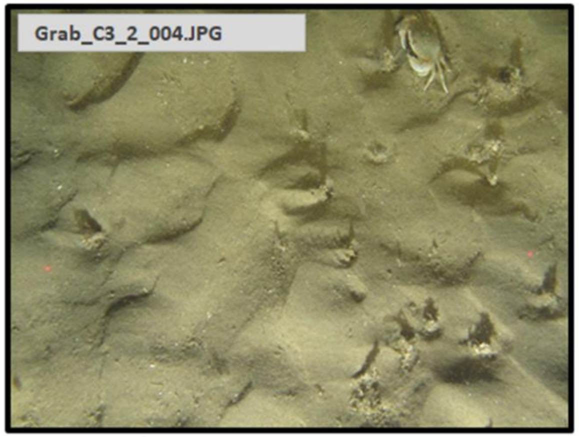


Photo Position: 725364 mE, 5953617 mN

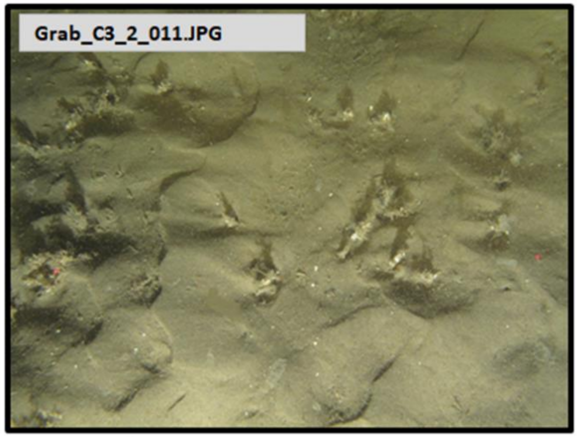


Photo Position: 725359 mE, 5953640 mN

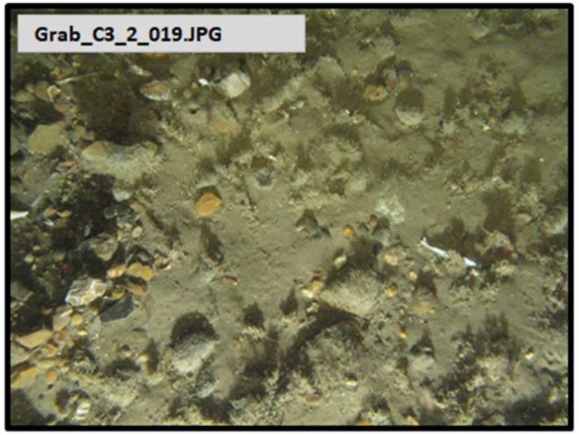


Photo Position: 725352 mE, 5953671 mN

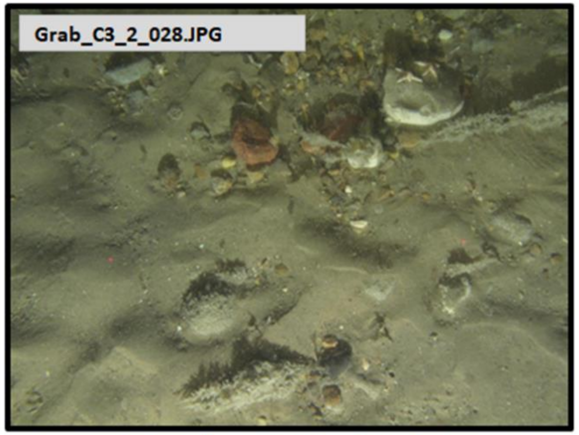
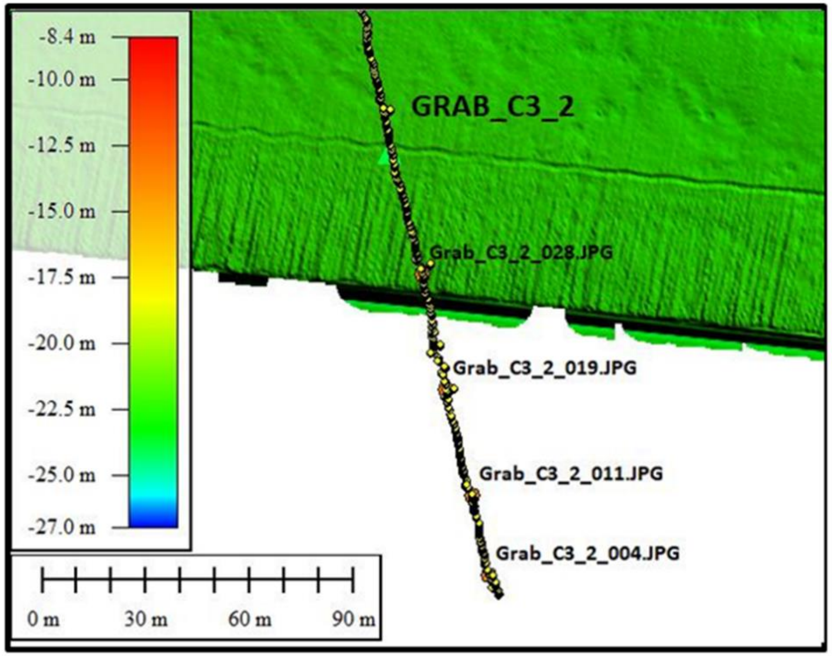


Photo Position: 725345 mE, 5953704 mN



Sediment Example Image

Grab Location | Camera Track | Selected Underwater Still

Sieved Sample Image

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

Habitat Summary Information: North Transect 1

Survey Area: N5a

No. of Stills: 30 **Mins of Video: 10** **Track Length: 135m**

Site Selection Criteria

Investigating transition from mixed to high reflectivity sediment.

Analogue Interpretation

Area of higher, variable reflectivity with many raised areas.

Sediment Description

Slightly gravelly/shelly coarse sand forming irregular ripples or *Lanice conchilega* aggregations.

Conspicuous Fauna

Cnidaria: Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Cancer pagurus* (Edible crab), *Pagurus bernhardus* (Common hermit crab), Paguridae sp., *Liocarcinus* sp., Brachyura sp., *Cancer maenus* . **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** *Limanda limanda* (Dab), Pleuronectiformes sp., Actinopterygii sp.

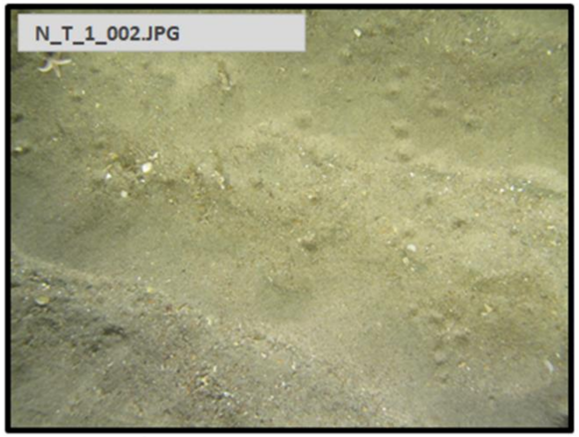


Photo Position: 721487 mE, 5954680 mN

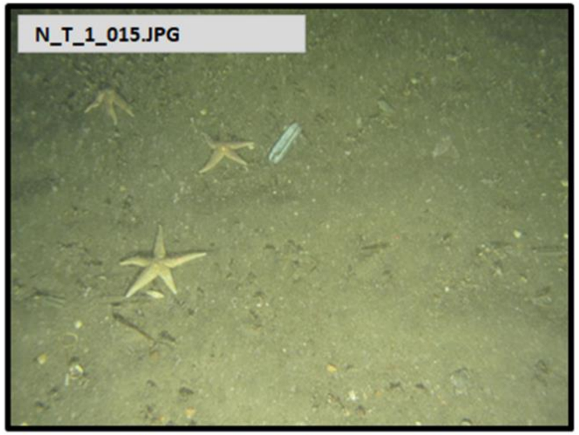


Photo Position: 721432 mE, 5954659 mN

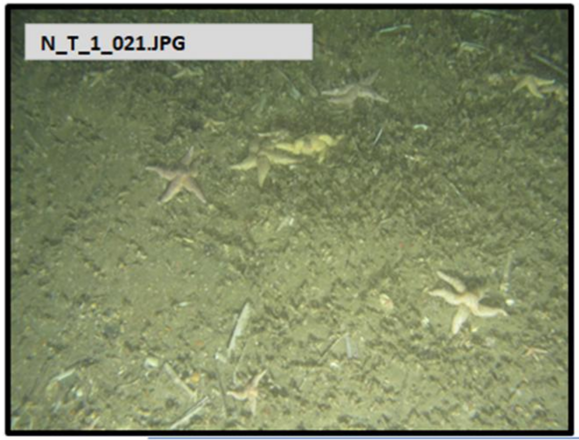
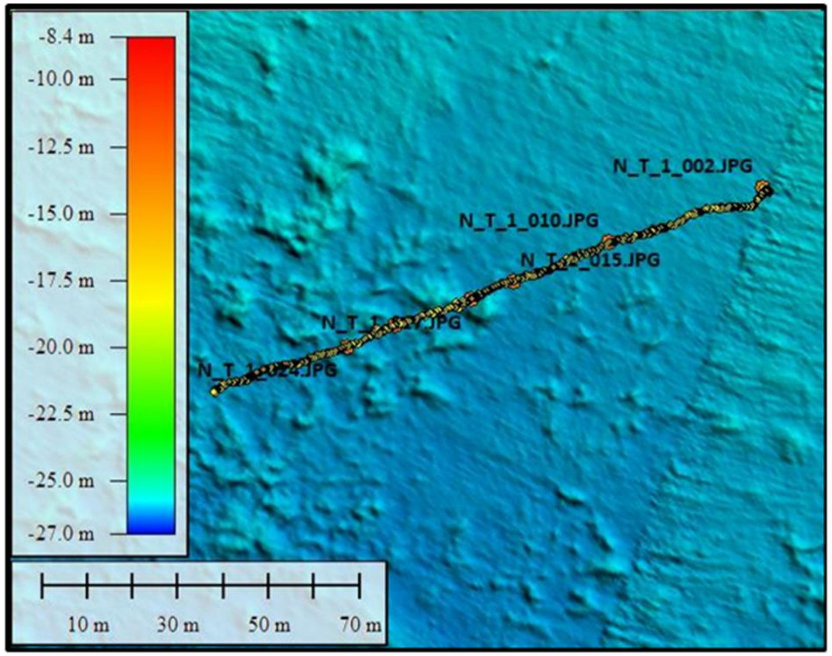


Photo Position: 721406 mE, 5954650 mN



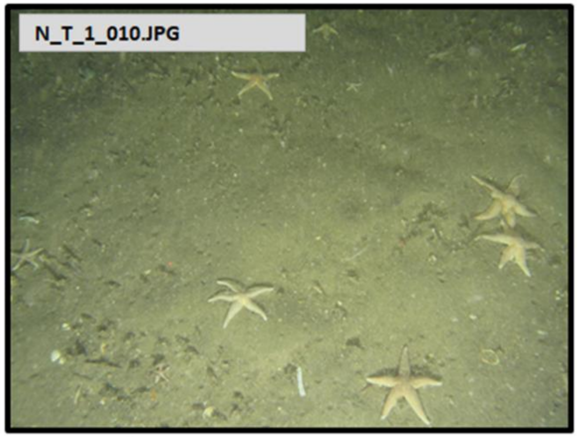


Photo Position: 721453 mE, 5954668 mN

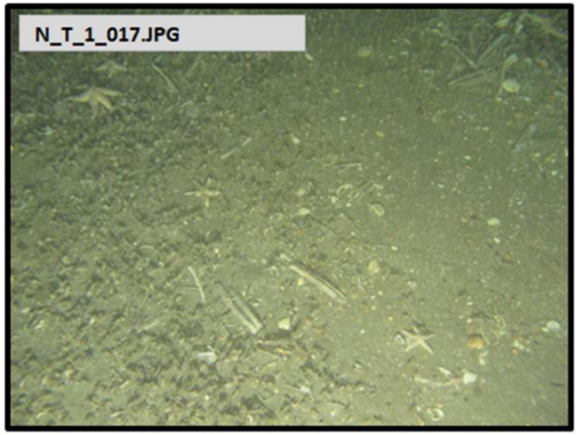


Photo Position: 721423 mE, 5954655 mN

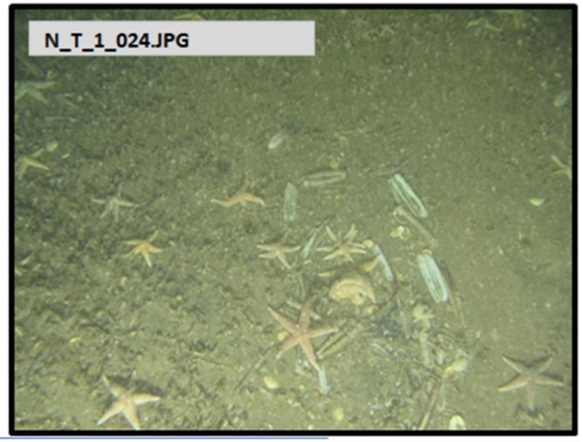


Photo Position: 721395 mE, 5954645 mN

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: North Transect 2

Survey Area: N5a

No. of Stills: 41 **Mins of Video: 13** **Track Length: 165m**

Site Selection Criteria

Investigating transition from low to mixed reflectivity sediment.

Analogue Interpretation

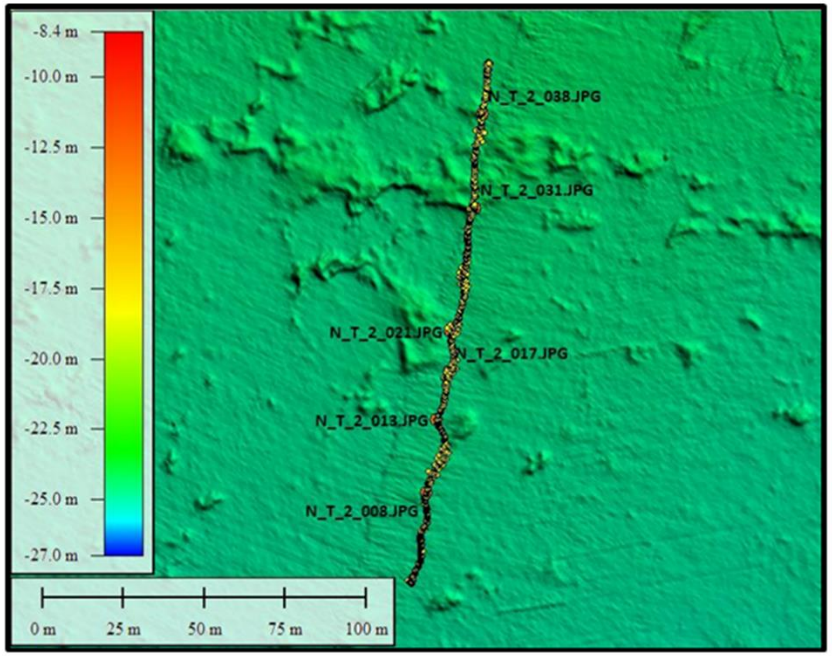
Area of higher, variable reflectivity with raised areas.

Sediment Description

Slightly gravelly/shelly coarse sand forming irregular ripples or *Lanice conchilega* aggregations.

Conspicuous Fauna

Cnidaria: Cerianthidae sp, Cerianthidae sp. **Annelida:** *Lanice conchilega* . **Arthropoda:** *Cancer pagurus* , *Pagurus bernhardus* , Paguridae sp., *Liocarcinus* sp., Brachyura sp., *Cancer maenus* . **Echinodermata:** *Asterias rubens* . **Chordata:** *Callionymus lyra* , Pleuronectiformes sp., Actinopterygii sp.



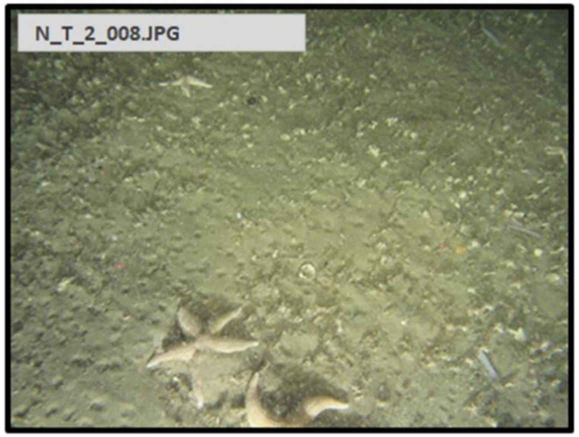


Photo Position: 721613 mE, 5955020 mN

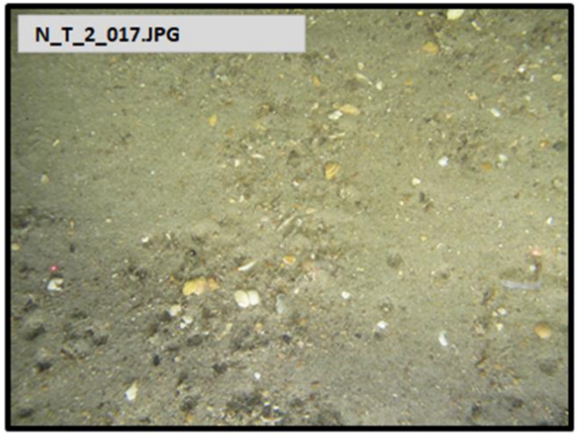


Photo Position: 721620 mE, 5955057 mN

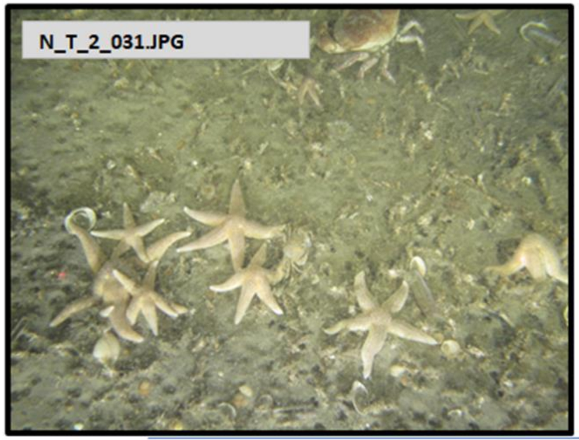


Photo Position: 721628 mE, 5955108 mN

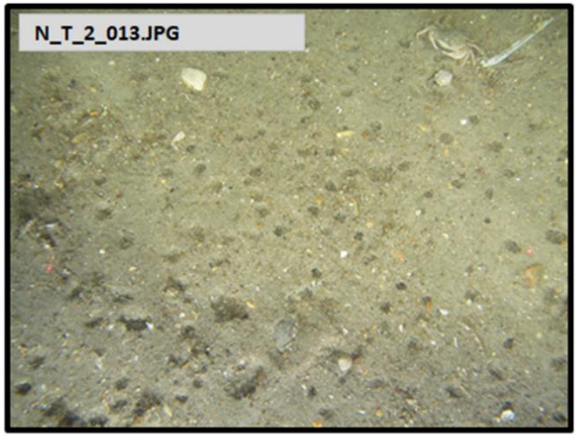


Photo Position: 721616 mE, 5955043 mN

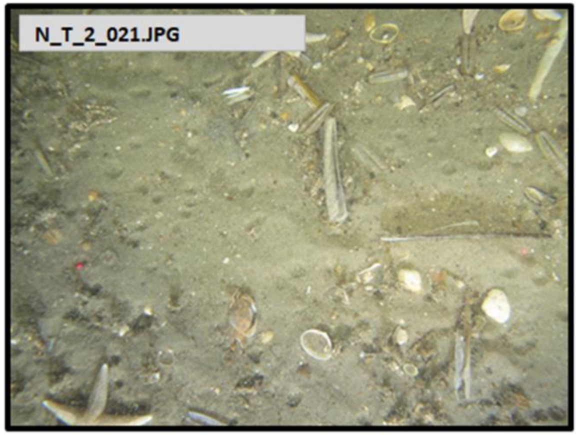


Photo Position: 721621 mE, 5955070 mN

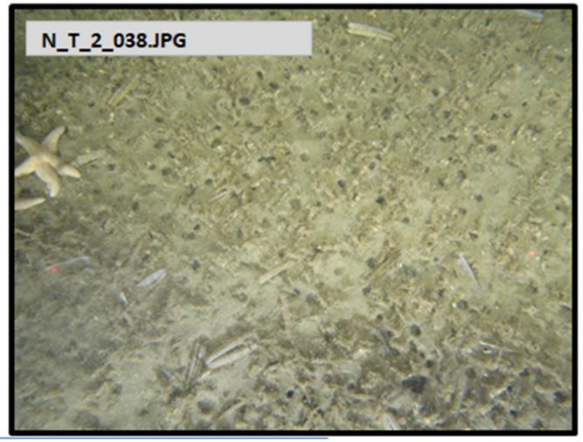


Photo Position: 721630 mE, 5955137 mN

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

Habitat Summary Information: North Transect 3

Survey Area: N5a

No. of Stills: 50 Mins of Video: 13 Track Length: 175m

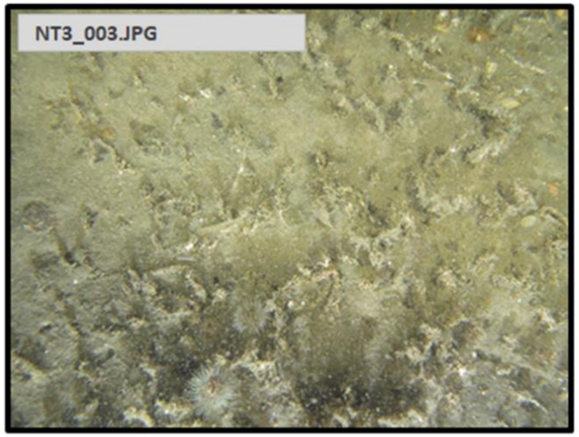


Photo Position: 721903 mE, 5954408 mN

Site Selection Criteria

Investigating transition from mixed to high reflectivity sediment.

Analogue Interpretation

Area of variable reflectivity, some apparent scarring on seabed.

Sediment Description

Slightly gravelly/shelly coarse sand forming irregular ripples or Lanice conchilega aggregations.

Conspicuous Fauna

Cnidaria: *Metridium senile* (Plumose Anemone), Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Cancer pagurus* (Edible crab), *Pagurus bernhardus* (Common hermit crab), Paguridae sp., *Liocarcinus* sp., Brachyura sp., *Cancer maenus*. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** *Callionymus lyra* (Common dragonet), Gobiidae sp., Pleuronectiformes sp., Actinopterygii sp., *Eutrigla gurnardus* (Grey gurnard).

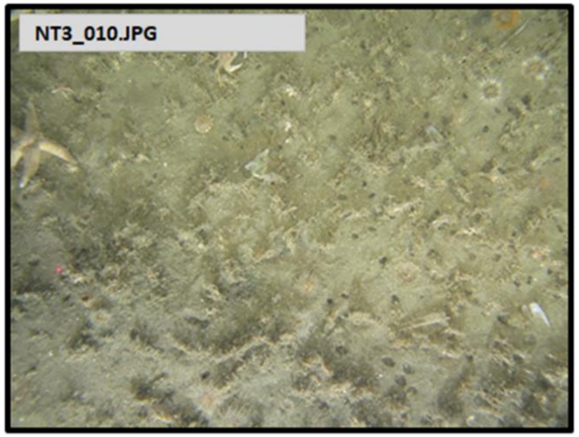


Photo Position: 721891 mE, 5954426 mN

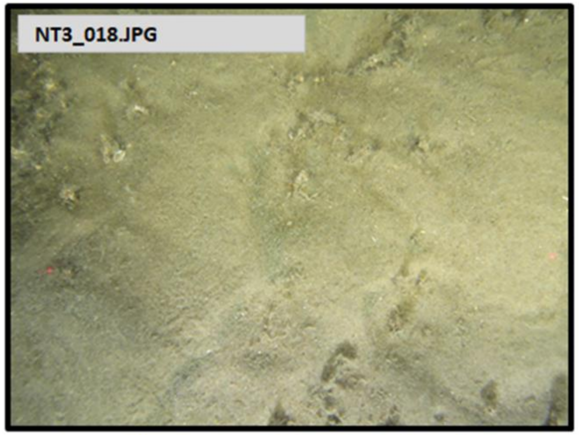
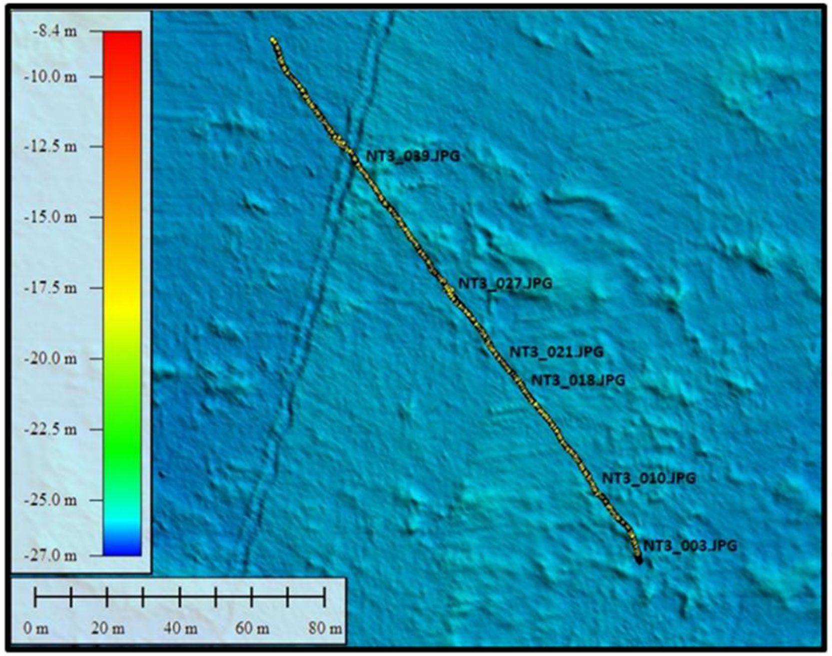


Photo Position: 721872 mE, 5954453 mN



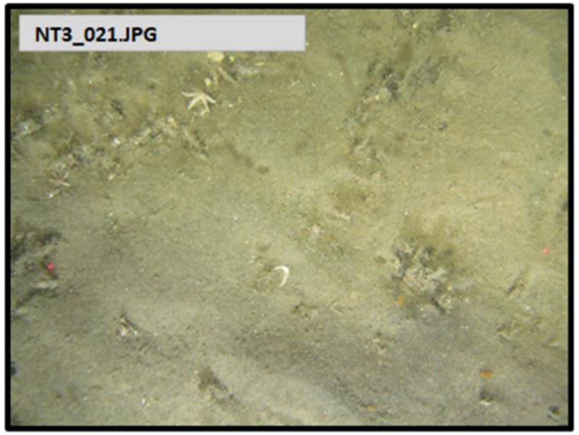


Photo Position: 721866 mE, 5954461 mN

Photo Position: 721852 mE, 5954480 mN

onedyas benthic solutions limited GEOXYZ OFFSHORE

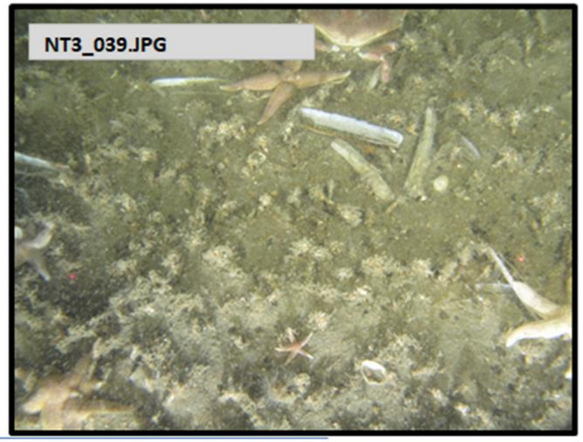


Photo Position: 721852 mE, 5954480 mN

Grab Location Camera Track Selected Underwater Still

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

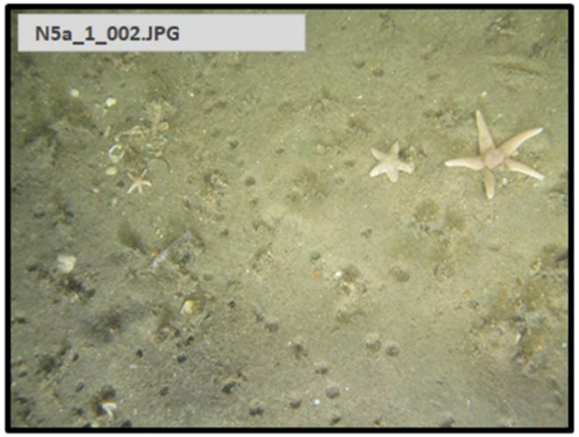


Photo Position: 721585 mE, 5954589 mN

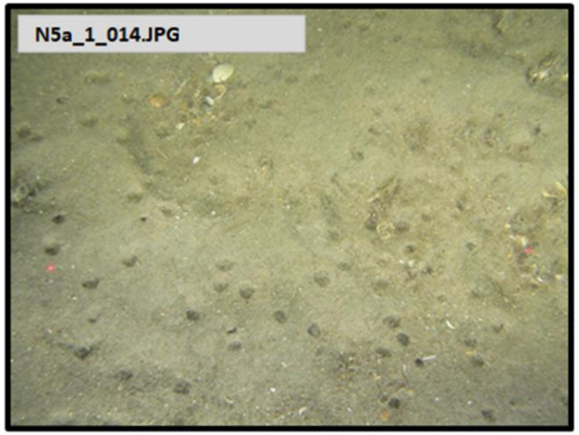


Photo Position: 721600 mE, 5954631 mN

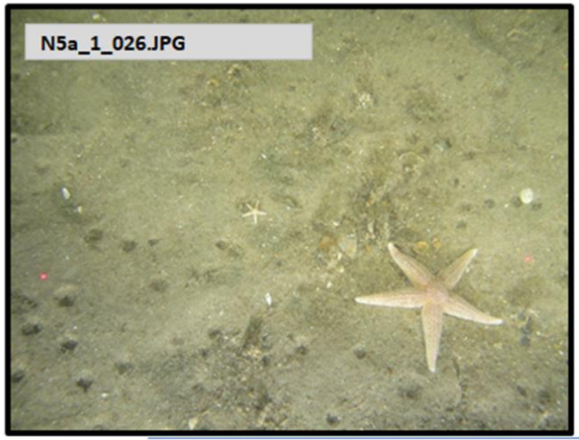


Photo Position: 721616 mE, 5954677 mN

Habitat Summary Information: N5a Transect 1

Survey Area: N5a

No. of Stills: 35 | Mins of Video: 9 | Track Length: 130m

Site Selection Criteria

Transect across original N5a well location.

Analogue Interpretation

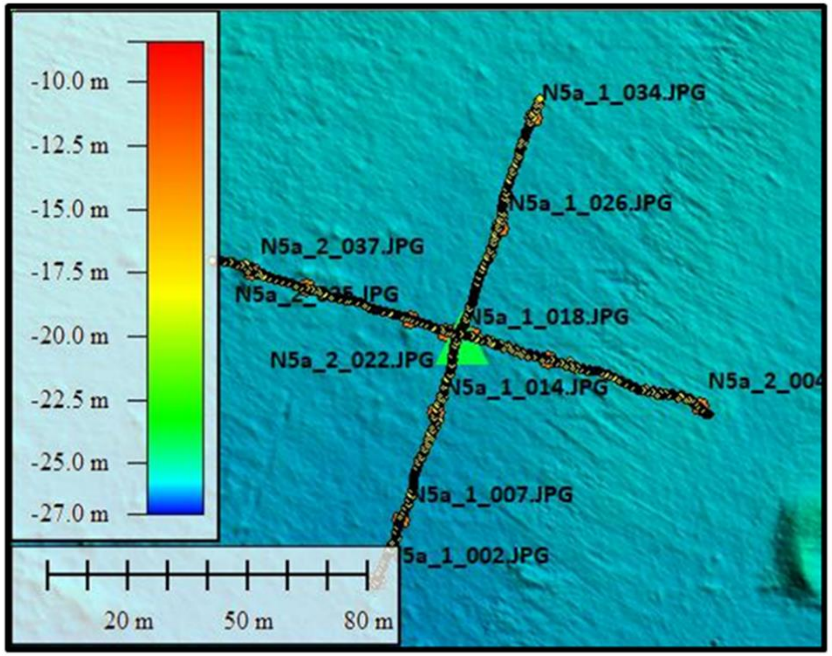
Area of low reflectivity with some scarring.

Sediment Description

Slightly gravelly/shelly coarse sand.

Conspicuous Fauna

Cnidaria: *Metridium senile* (Plumose Anemone), Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Cancer pagurus* (Edible crab), Paguridae sp., *Liocarcinus* sp., Brachyura sp., *Cancer maenus* . **Mollusca:** *Sepiola* sp. **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** *Callionymus lyra* (Common dragonet), Pleuronectiformes sp., Actinopterygii sp., *Eutrigla gurnardus* (Grey gurnard).



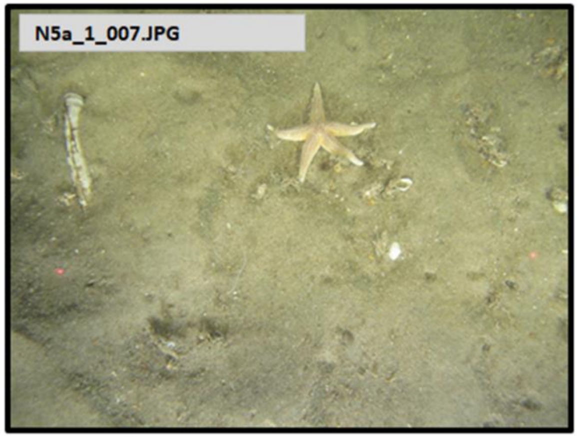


Photo Position: 721592 mE, 5954605 mN

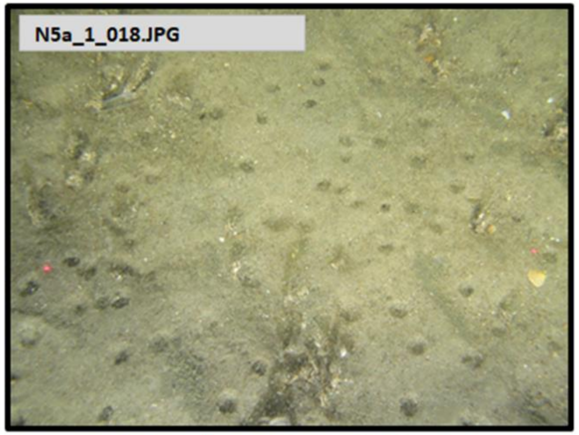


Photo Position: 721606 mE, 5954649 mN

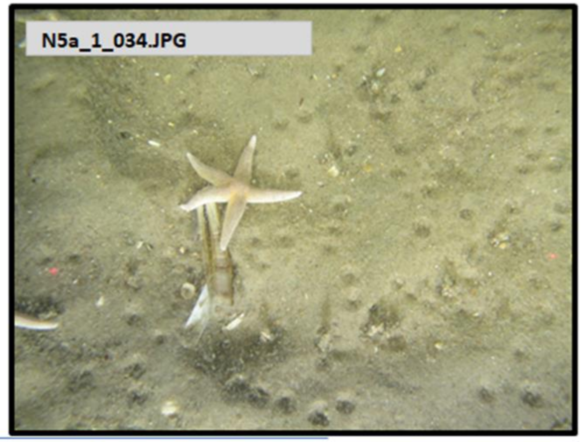


Photo Position: 721625 mE, 5954705 mN

Grab Location | Camera Track | Selected Underwater Still

Geodetic Infomation: Datum: ED50 | Projection: UTM | Zone: 31 North | Central Meridian: 3° East

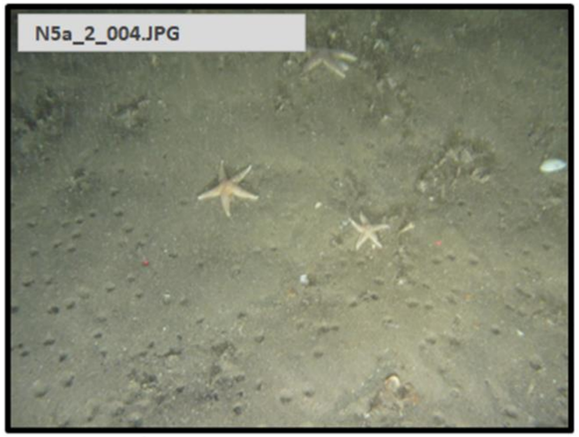


Photo Position: 721613 mE, 5955020 mN

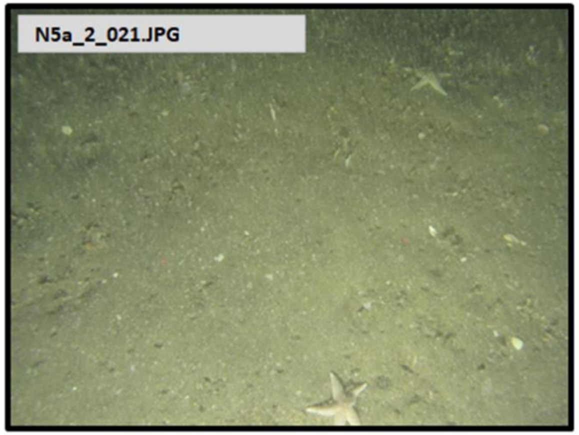


Photo Position: 721620 mE, 5955057 mN

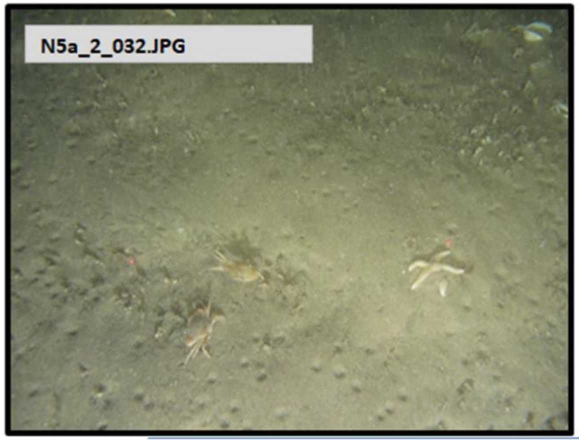


Photo Position: 721628 mE, 5955108 mN

Habitat Summary Information: N5a Transect 2

Survey Area: N5a

No. of Stills: 39 **Mins of Video: 9** **Track Length: 130m**

Site Selection Criteria

Transect across original N5a well location.

Analogue Interpretation

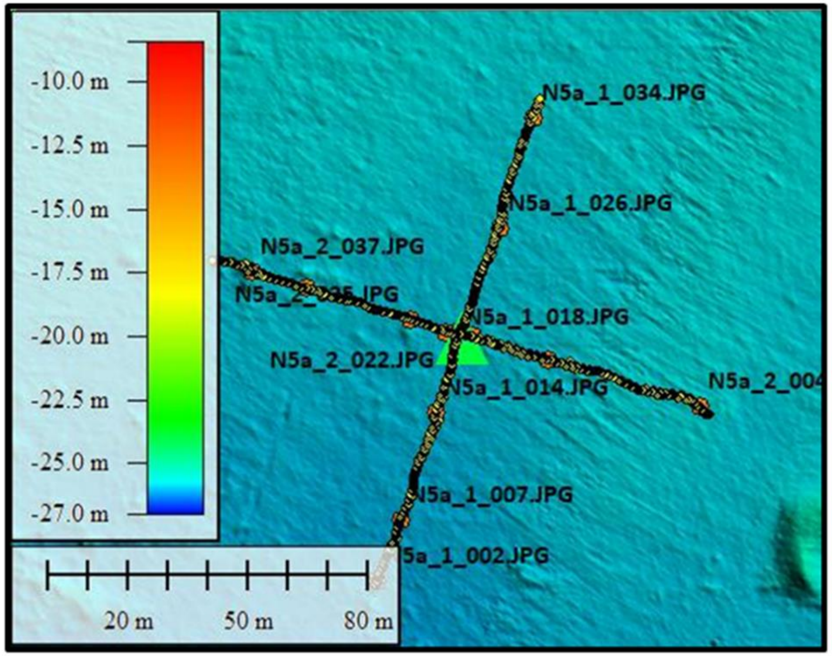
Area of low reflectivity with some scarring.

Sediment Description

Slightly gravelly/shelly coarse sand and aggregations of *Lanice conchilega* .

Conspicuous Fauna

Cnidaria: *Metridium senile* (Plumose Anemone), Cerianthidae sp. **Annelida:** *Lanice conchilega* (Sand Mason). **Arthropoda:** *Cancer pagurus* (Edible crab), Paguridae sp., *Liocarcinus* sp., Brachyura sp., *Cancer maenus* . **Echinodermata:** *Asterias rubens* (Common starfish). **Chordata:** *Callionymus lyra* (Common dragonet), Pleuronectiformes sp., Actinopterygii sp.



Grab Location | Camera Track | Selected Underwater Still

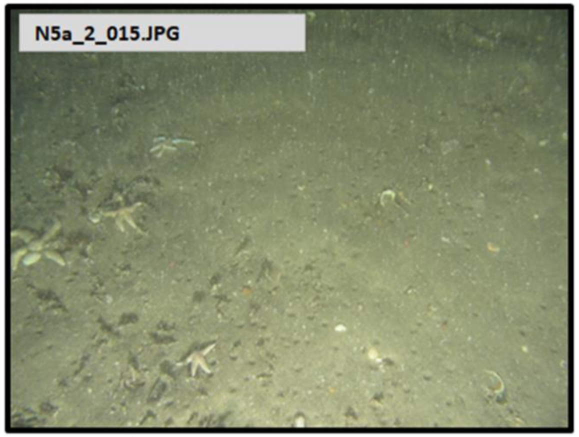


Photo Position: 721616 mE, 5955043 mN

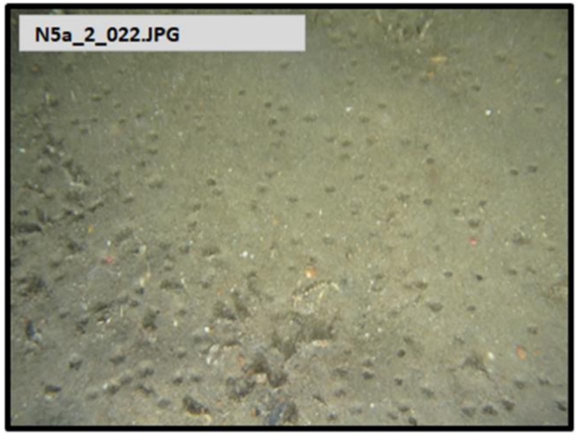


Photo Position: 721621 mE, 5955070 mN

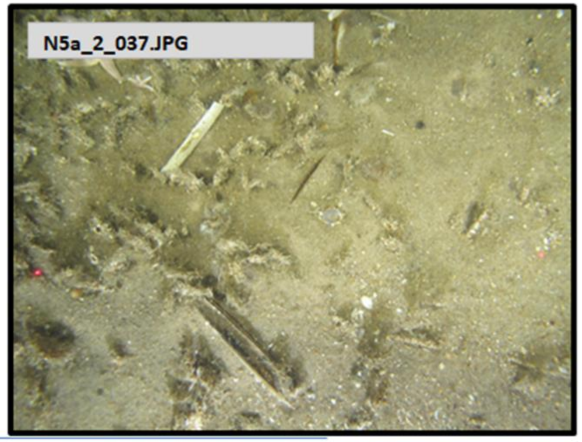


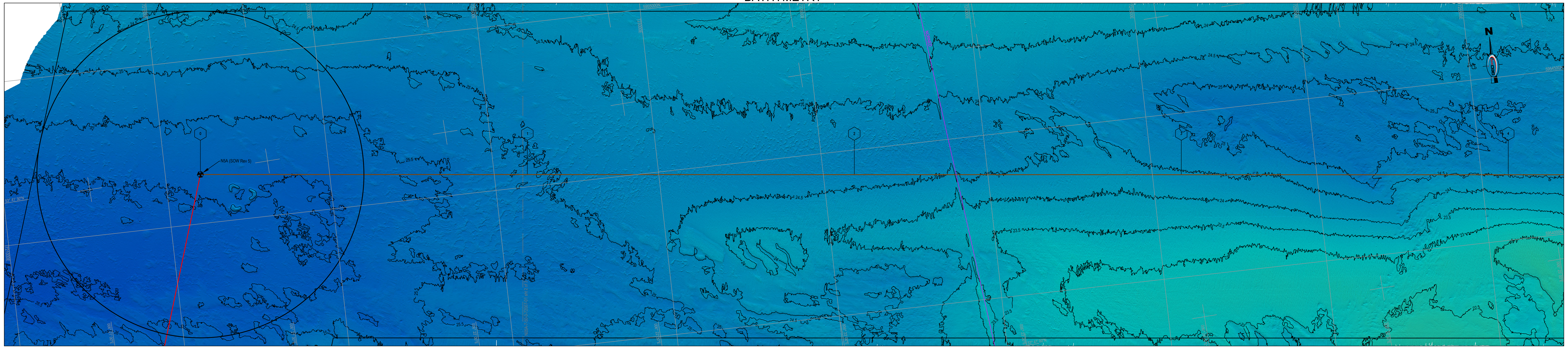
Photo Position: 721630 mE, 5955137 mN

Geodetic Infomation: Datum: ED50 Projection: UTM Zone: 31 North Central Meridian: 3° East

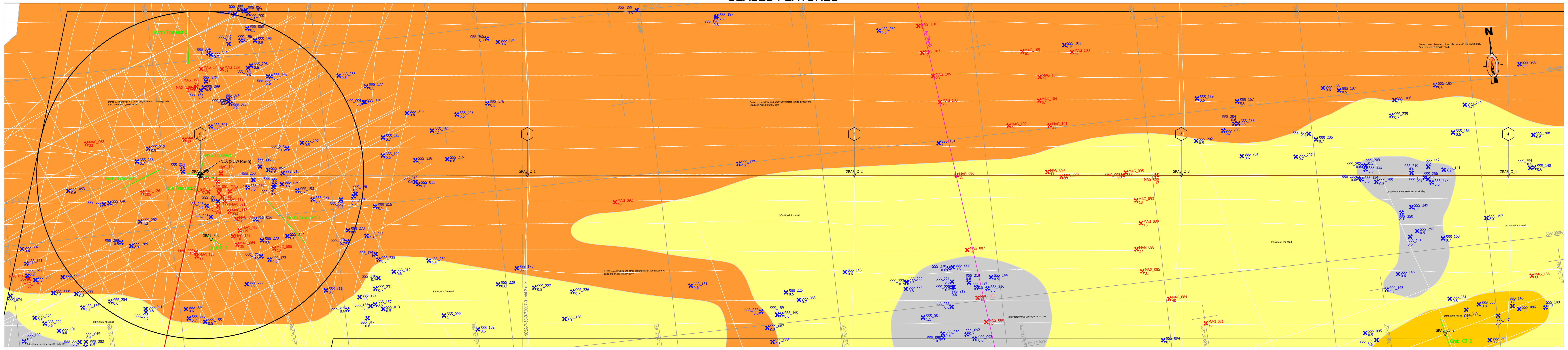
APPENDIX E – SERVICE WARRANTY

This report, with its associated works and services, has been designed solely to meet the requirements of the contract agreed with you, our client. If used in other circumstances, some or all of the results may not be valid and we can accept no liability for such use. Such circumstances include different or changed objectives, use by third parties, or changes to, for example, site conditions or legislation occurring after completion of the work. In case of doubt, please consult Benthic Solutions Limited. Please note that all charts, where applicable should not be used for navigational purposes.

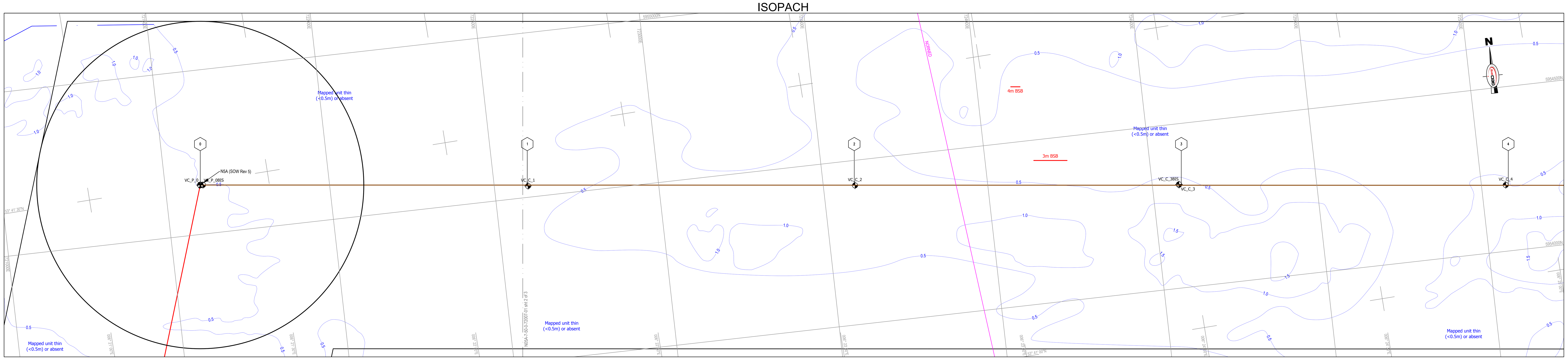
BATHYMETRY



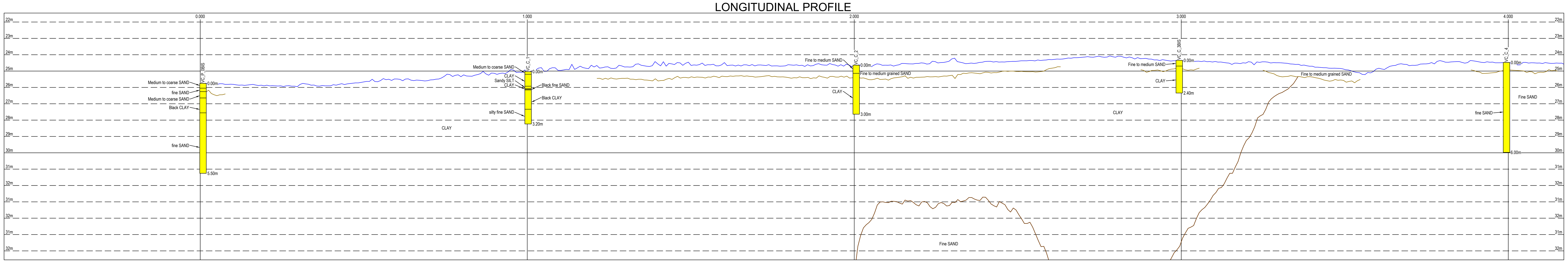
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

- Kilometer point
- Chart match lines
- Survey Area (500m at each side of proposed pipeline/cable)
- Proposed pipeline route
- Proposed cable route
- Natura 2000
- Cables
- Pipelines
- 500m zone
- Proposed new location for N5A platform
- Internal cables Riffgat
- Monopile location Riffgat
- Graticule grid
- U.T.M. grid

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals
Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m Height (m)

SEABED FEATERS:

- Vessel track
- Linear debris
- Camera transects
- SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m
- MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT
- DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)
- GRAB_P_12 — Position of grab sample

- Infralittoral fine sand (A5.23)
- Infralittoral coarse sediment (A5.13)
- Infralittoral mixed sediment (A5.43) - no clay
- Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)
- Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

- 1.0 contour at 0.5 metre intervals
- Data extents
- Shallow gas
- VC_C_4 — Position of vibrocore

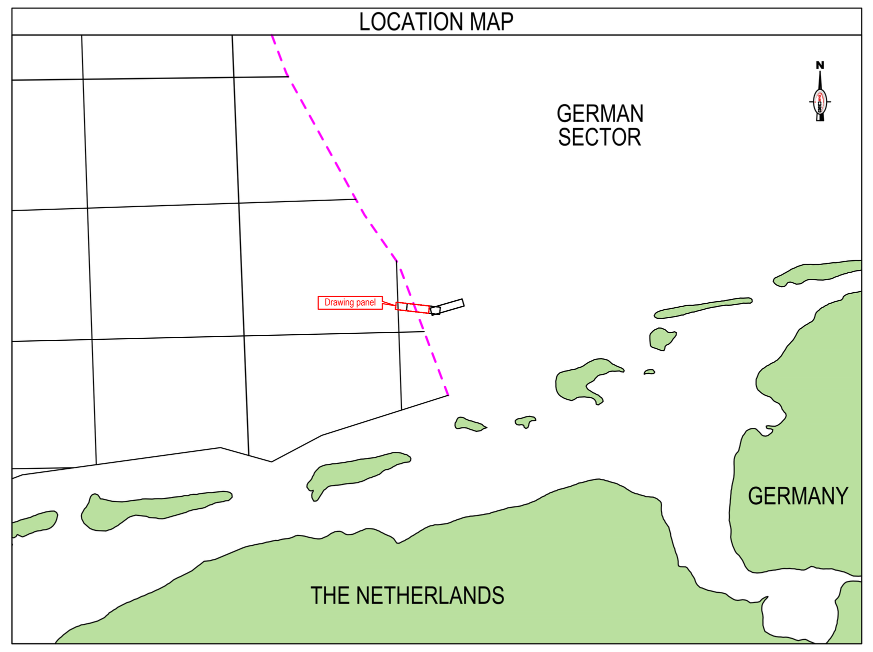
LONGITUDINAL PROFILE:

- Seabed
- Base surfical sand
- Clay
- Kilometer point

VC_C_1 — Name of vibrocore
0.00m
4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

SURVEY SOFTWARE

Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
Semi-major axis:	a = 6378388.00m
Semi-minor axis:	b = 6356911.95m
First eccentricity squared:	e2 = 0.006723
Inverse flattening:	1/f = 297.000
EPSG code:	23031
Projection:	UTM31N
Central meridian:	03° east
Latitude of origin:	0°
False easting:	500000.00m
False northing:	0.00m
Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):

Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO RIFFGAT

Cable route

KP 0.000 to 4.170

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 001/003	Scale: 1/5000	LAT

Drawing made by:

GEOXYZ OFFSHORE
2 Route D'Arlon
Windhof Business center block A
L-8388 WINDHOF
Luxembourg

Client:

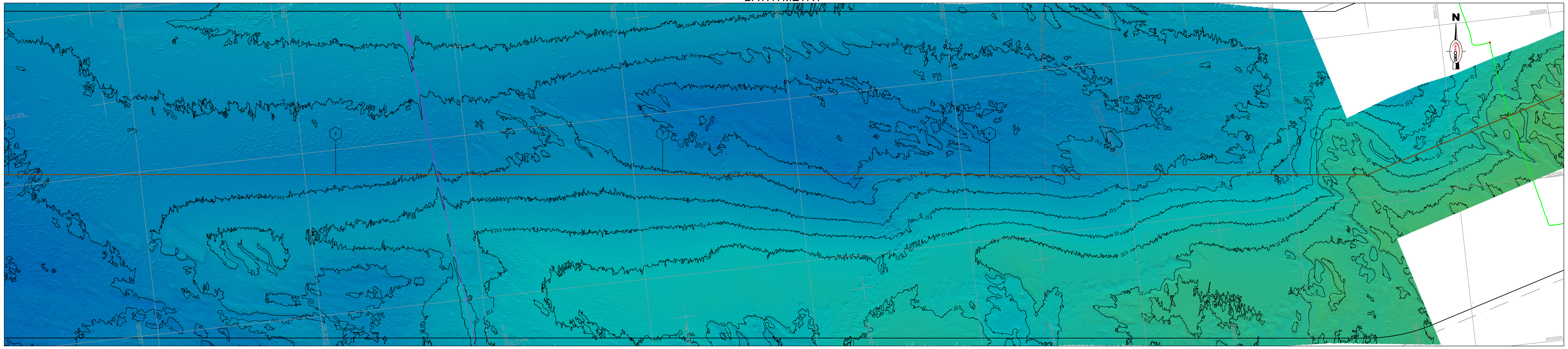
Oranje-Nassau Energie B.V.
UNStudio, 7th floor
Parnassusweg 815
1082 LZ Amsterdam (The Netherlands)

Tel: +31 20 535 41 00
Fax: +31 20 535 41 22

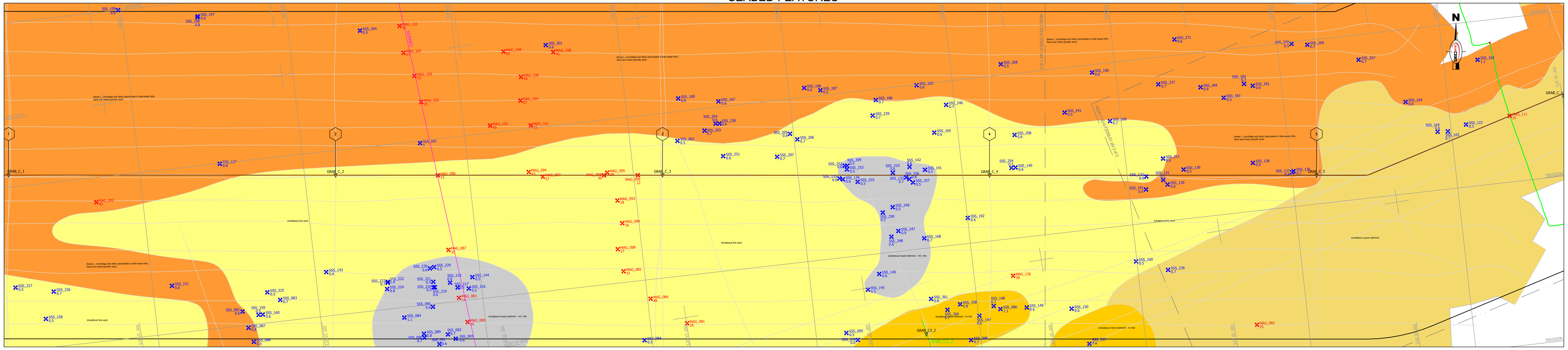
Issue no:	Date:	Description:	Drawn:	Checked:
1	12/06/2019	Second internal review	STH	RSP/TDB
2	15/07/2019	Issued for use	STH	RSP/TDB
3	05/09/2019	Client remarks	STH	RSP/TDB
4	01/10/2019	Client remarks	STH	RSP/TDB

Planname:	LU0022H-553_DR-004_CR_1-3_v4.0	Project ref:	N05A-7-50-0-72006-01 sht 1 of 3

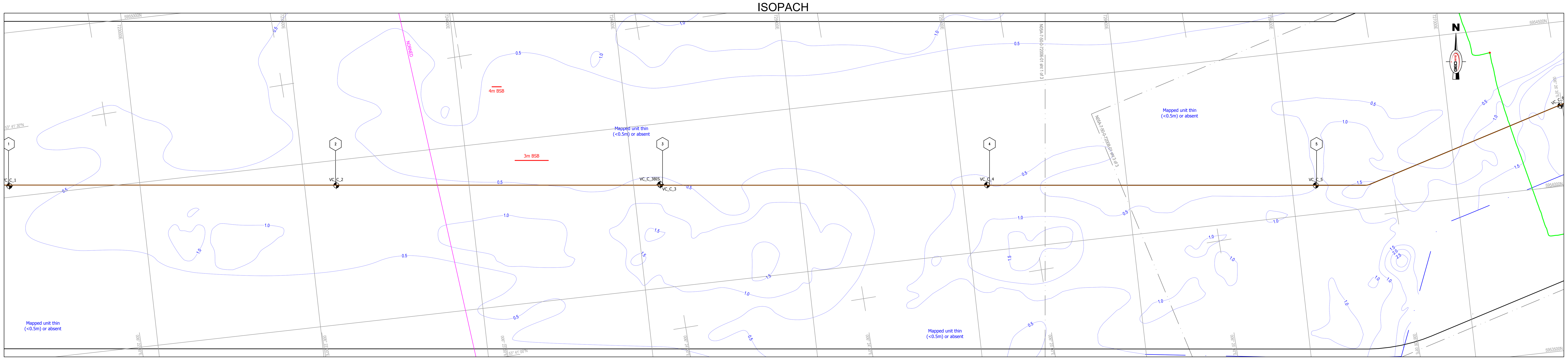
BATHYMETRY



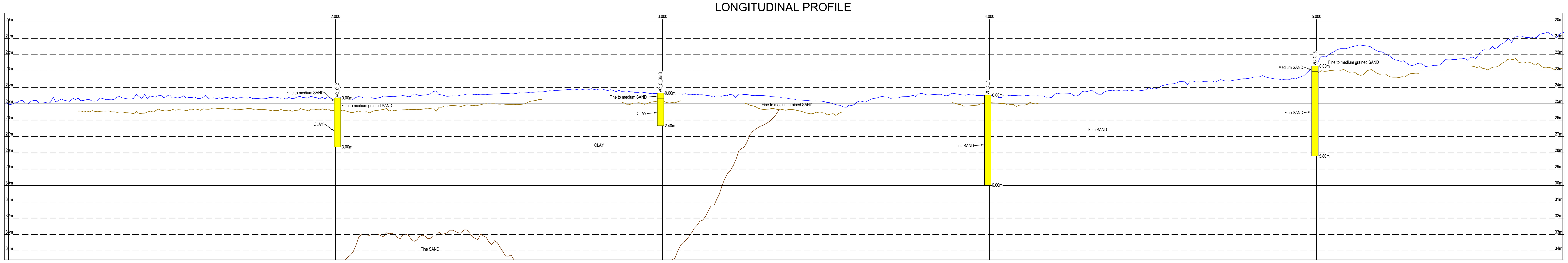
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

Kilometer point

SCALE 1:5000 — 0, 50, 100, 150, 200, 250, 500 meters; 0, 200, 400, 800, 1600 feet

- Chart match lines
- Survey Area (500m at each side of proposed pipeline/cable)
- Proposed pipeline route
- Proposed cable route
- Natura 2000
- Cables
- Pipelines
- 500m zone
- Proposed new location for N5A platform
- Internal cables Riffgat
- Monopile location Riffgat
- Graticule grid
- U.T.M. grid

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 — Depth contour at 0.5 meter intervals
Gridsize used for contours: 0.5m

-35m, -30, -25, -20, -15, -10, -5m
Gridsize: 0.5m — Height (m)

SEABED FEATERS:

- Vessel track
- Linear debris
- Camera transects
- SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m
- MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT
- DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)
- GRAB_P_12 — Position of grab sample

- Infralittoral fine sand (A5.23)
- Infralittoral coarse sediment (A5.13)
- Infralittoral mixed sediment (A5.43) - no clay
- Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)
- Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

- 1.0 — contour at 0.5 metre intervals
- Data extents
- Shallow gas
- VC_C_4 — Position of vibrocore

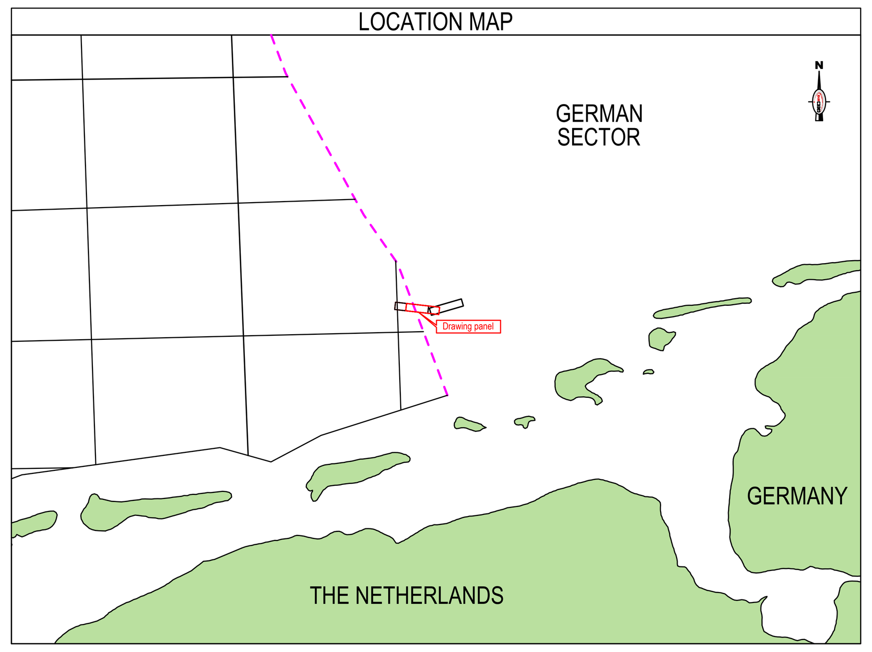
LONGITUDINAL PROFILE:

- Seabed
- Base surfical sand
- Clay
- 4.000 — Kilometer point

VC_C_1 — Name of vibrocore
0.00m
4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

SURVEY SOFTWARE

Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
Semi-major axis:	a = 6378388.00m
Semi-minor axis:	b = 6356911.95m
First eccentricity squared:	e2 = 0.006723
Inverse flattening:	1/f = 297.000
EPSG code:	23031
Projection:	UTM31N
Central meridian:	03° east
Latitude of origin:	0°
False easting:	500000.00m
False northing:	0.00m
Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):
Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO RIFFGAT

Cable route
KP 0.986 to 5.756

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 002/003	Scale: 1/5000	LAT

Drawing made by:

GEOXYZ OFFSHORE
2 Route D'Arlon
Windhof Business center block A
L-8388 WINDHOF
Luxembourg

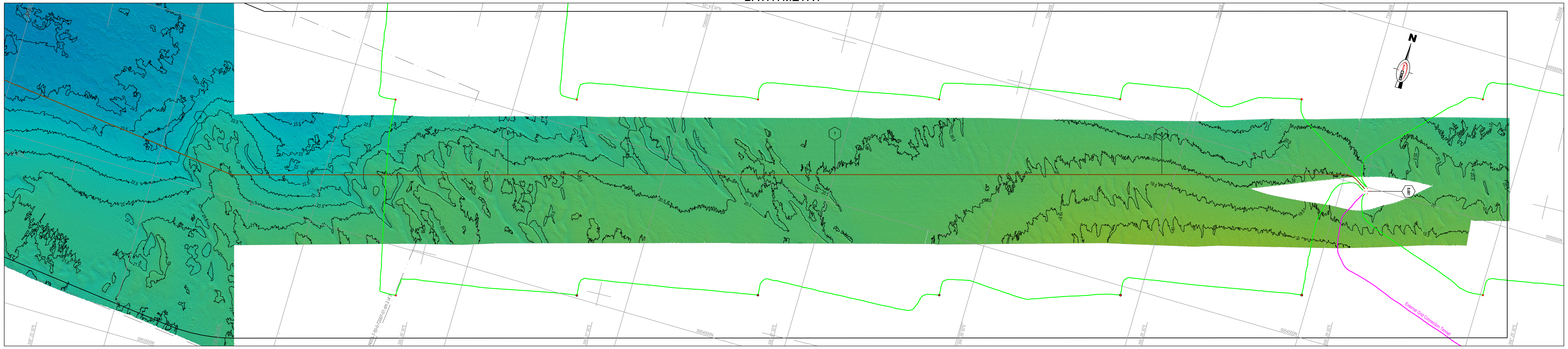
Client:

Oranje-Nassau Energie B.V.
UNStudio, 7th floor
Parnassusweg 815
1082 LZ Amsterdam (The Netherlands)
Tel: +31 20 535 41 00
Fax: +31 20 535 41 22

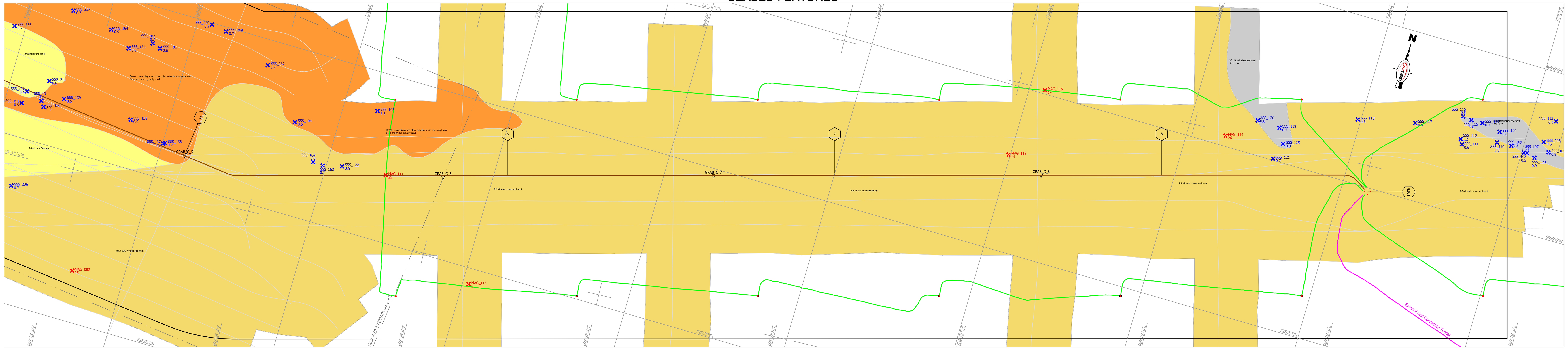
Issue no:	Date:	Description:	Drawn:	Checked:
1	12/06/2019	Second internal review	STH	RSP/TDB
2	15/07/2019	Issued for use	STH	RSP/TDB
3	05/09/2019	Client remarks	STH	RSP/TDB
4	01/10/2019	Client remarks	STH	RSP/TDB

Planname:	LU0022H-553_DR-005_CR_2-3_v4.0	Project ref:	N05A-7-50-0-72007-01 sht 2 of 3

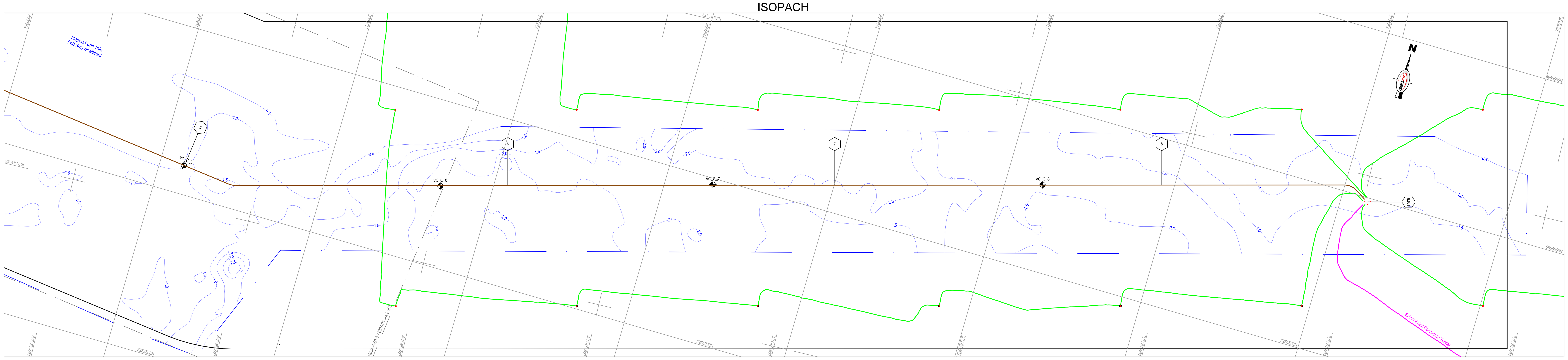
BATHYMETRY



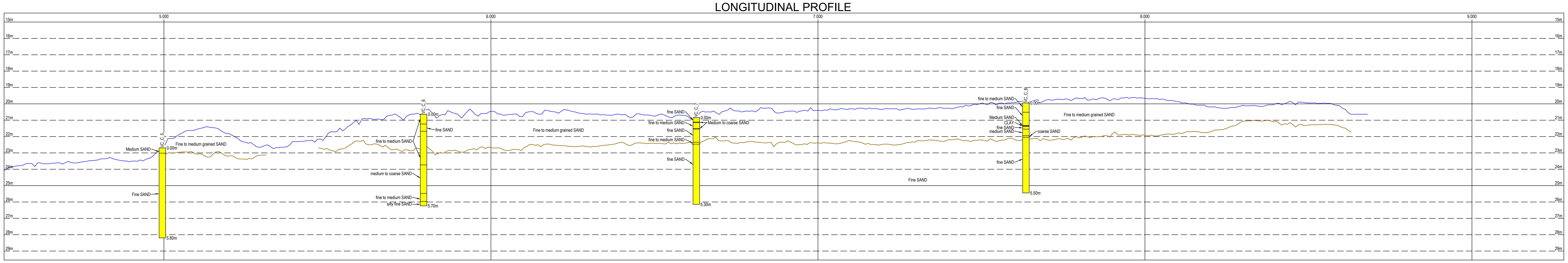
SEABED FEATURES



ISOPACH



LONGITUDINAL PROFILE



LEGEND

Kilometer point

SCALE 1:5000

0 50 100 150 200 250 500 meters

0 200 400 800 1600 feet

Chart match lines

Survey Area (500m at each side of proposed pipeline/cable)

Proposed pipeline route

Proposed cable route

Natura 2000

Cables

Pipelines

500m zone

Proposed new location for N5A platform

Internal cables Riffgat

Monopile location Riffgat

Graticule grid

U.T.M. grid

BATHYMETRY:

All Bathymetry reduced to Lowest Astronomical Tide (LAT)

20 Depth contour at 0.5 meter intervals

Gridsize used for contours: 0.5m

-35m -30 -25 -20 -15 -10 -5m

Gridsize: 0.5m

Height (m)

SEABED FEATERS:

Vessel track

Linear debris

Camera transects

SSS_266 0.8 — Object ID; SSS contact/object: Unit value: m

MAG_158 0.6 — Object ID; Magnetic contact: Unit value: nT

DEB_023 1.4 x 0.5 x 0.3 — Object ID; Debris: Unit value: m (Nmh: No measurable height)

GRAB_P_12 — Position of grab sample

Infralittoral fine sand (A5.23)

Infralittoral coarse sediment (A5.13)

Infralittoral mixed sediment (A5.43) - no clay

Dense L. conchilega and other polychaetes in tide-swept infra. Sandand mixed gravelly sand (A5.137)

Infralittoral mixed sediment (A5.43) - Incl. clay

ISOPACH:

1. Time depth conversion carried out using an assumed seismic velocity (ASV) of 1600m/s.
2. The mapped unit is expected to comprise dense SAND

1.0 contour at 0.5 metre intervals

Data extents

Shallow gas

VC_C_4 — Position of vibrocore

LONGITUDINAL PROFILE:

Seabed

Base surfical sand

Clay

Kilometer point

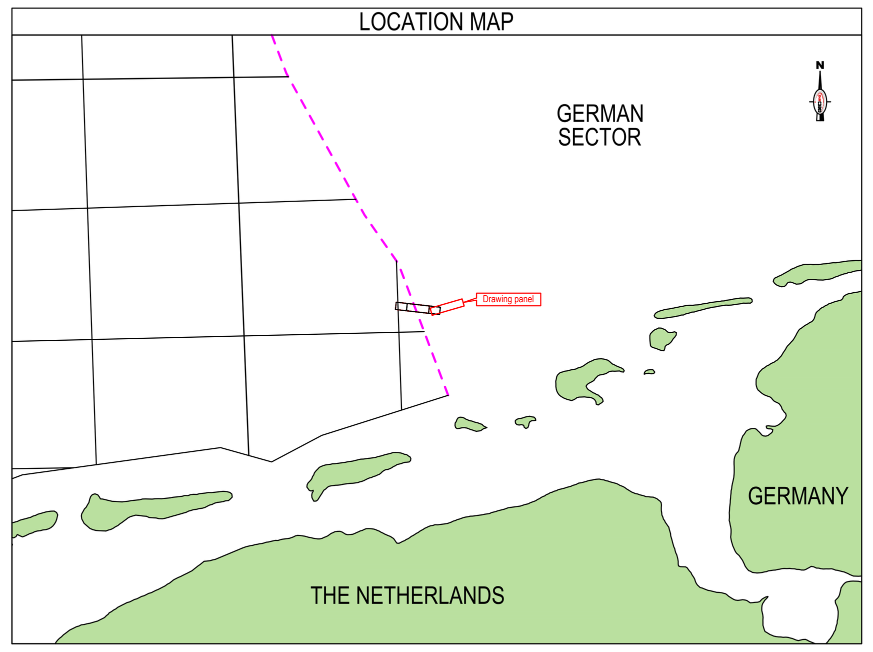
VC_C_1 — Name of vibrocore

0.00m

4.10m — Bottom - depth below seabed

ONE INFORMATION PANEL

LOCATION MAP



SURVEY EQUIPMENT

Positioning:	Fugro seastar 9205
Multibeam:	R2Sonic 2024
Motion sensor:	POS-MV OceanMaster
Sound velocity probe:	Valeport - Swift
Side scan sonar:	Edgetech - 4200
USBL:	Sonardyne Ranger 2
Magnetometer:	Geometrics - G882
Sub Bottom Profiler	Massa TR1075D
Seismic source:	GSO 180 Sparker

SURVEY SOFTWARE

Online/offline survey suite:	QINSy / Version 8.1
SSS Acquisition:	Edgetech Discover
SSS Processing:	CODA Survey Engine V. 4.3
SBP Acquisition:	Stema SILAS Acquisition
SBP Processing:	Stema SILAS Processing
MAG Acquisition:	QINSy / Version 8.1
MAG Processing:	Oasis Montaj

GEODETIC INFORMATION

Horizontal datum:	European datum 1950 (ED 50)
Spheroid:	International 1924
Semi-major axis:	a = 6378388.00m
Semi-minor axis:	b = 6356911.95m
First eccentricity squared:	e2 = 0.006723
Inverse flattening:	1/f = 297.000
EPSG code:	23031
Projection:	UTM31N
Central meridian:	03° east
Latitude of origin:	0°
False easting:	500000.00m
False northing:	0.00m
Scale factor at central meridian:	0.9996
Units:	Metres
Vertical datum:	Lowest astronomical tide (LAT)

SURVEY DATES

Geophysical acquisition (MBES, MAG, SSS, SBP):

Geo Ocean III: 29/04/2019 untill 15/05/2019

HYDROGRAPHIC SURVEY

N5A development - pipeline route & platform area survey

N5A TO RIFFGAT

Cable route

KP 4.511 to 8.681

Bathymetry - Seabed features - Isopach - Longitudinal profile

Chart: 003/003	Scale: 1/5000	LAT

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Issue no:	Date:	Description:	Drawn:	Checked:
1	12/06/2019	Second internal review	STH	RSP/TDB
2	15/07/2019	Issued for use	STH	RSP/TDB
3	05/09/2019	Client remarks	STH	RSP/TDB
4	01/10/2019	Client remarks	STH	RSP/TDB

Planname:	LU0022H-553_DR-006_CR_3-3_v4.0	Project ref:	N05A-7-50-0-72008-01 sht 3 of 3

N5A Development

Title	**Survey Report - N5A Platform to Riffgat Cable Route**
GEOxyz Report No.	LU0022H-553-RR-07
ONE Report No.	N05A-7-10-0-70023-01
Revision	2.0

2.0	07/08/2019	Issued for use				
1.1	03-07-2019	Review copy				
1.0	14-06-2019	First draft				
Revision	Date	Description of Revision	Author	Checked	Approved	Approved Client

REVISION HISTORY

The screen version of this document is always the CONTROLLED COPY. When printed it is considered a copy FOR INFORMATION ONLY, and it is the holder's responsibility that they hold the latest valid version.

Rev.	Reason for revision	Changes from previous version
1.0	Client review	N/A
1.1	Incorporating Client comments	Two instances of pipeline route being used altered to cable route
2.0	Issued for use	

TABLE OF CONTENT

TABLE OF FIGURES

TABLE OF TABLES

LIST OF REFERENCES

1. Oranje-Nassau Energie, 2019. N5A Development Project Scope of Work. Document Ref. N5A-7-10-0-70000-01.
2. Igeotest, 2019. N5A-Development-Pipeline Route and Platform Area Survey. Geotechnical Preliminary Results.
3. Fugro Geoconsulting Limited, 2016. Field operations and Preliminary results Report with Engineering Assessments – Well N5-1 (Ruby) Geotechnical Site Investigation. Project Ref. J11354-R-1(02). Prepared for Hansa Hydrocarbons Limited.

ABBREVIATIONS

The abbreviations listed below are used within this report. Where abbreviations used in this document are not included in this table, it may be assumed that they are either equipment brand names or company names.

	Description		Description
2DHR	Two-Dimensional High Resolution Seismic	PWL	Proposed Platform Location
ASV	Assumed Seismic Velocity	RWL	Relief Platform Location
BSB	Below Seabed	SBES	Single-Beam Echosounder
CM	Central Meridian	SBP	Sub Bottom Profiler
DTU15	Technical University Denmark	SPI	Shot Point Interval
ED50	European Datum 1950	SSS	Side-Scan Sonar
km	Kilometre	TWT	Two-Way Travel Time
LAT	Lowest Astronomical Tide	UHR	Ultra-High Resolution Seismic
m	Metre	UKHO	UK Hydrographic Office
MBES	Multibeam Echosounder	USBL	Ultra-Short Base Line
MODU	Mobile Offshore Drilling Unit	UTC	Coordinated Universal Time
m/s	Metres per Second	UTM	Universal Transverse Mercator
ms	Milliseconds	UXO	Unexploded Ordnance
MSL	Mean Sea-level	WGS84	World Geodetic System 1984

1 EXECUTIVE SUMMARY

1.1 LOCATION OVERVIEW

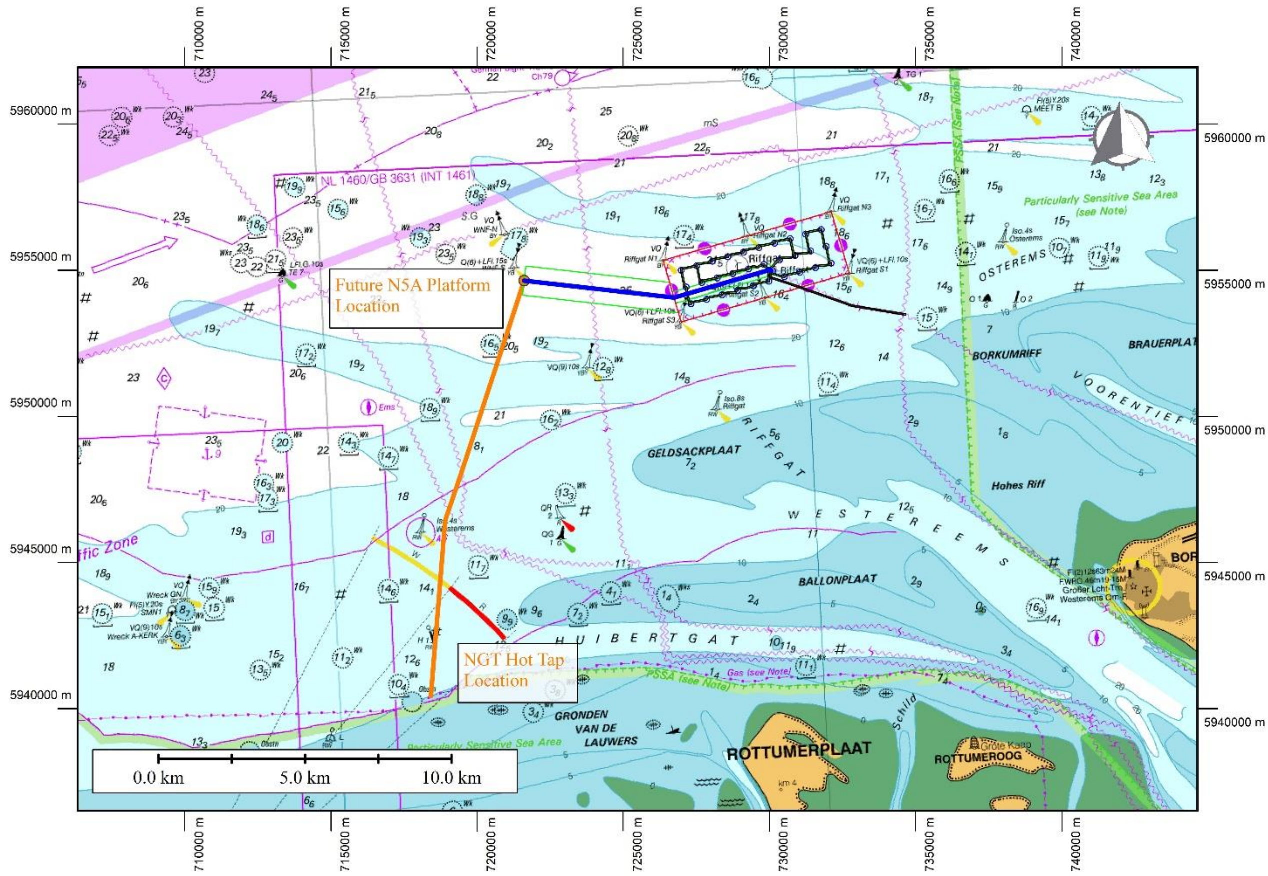


Figure 1: Project location overview

1.1 N5A TO RIFFGAT CABLE ROUTE ASSESSMENT

Proposed Cable Route Corridor		
Start location coordinates (N5A Platform Location)	721 607.00mE	53° 41' 32.347" N
	5 954 650.00mN	06° 21' 23.281" E
End location coordinates (Riffgat Windpark Transformer Station Location)	730 081.00m E	53° 41' 30.080" N
	5 954 988.00m N	06° 29' 05.312" E
Geodesy	ED50 : UTM Zone 31N : CM 3° E	
Vertical Datum	All depths are in metres below LAT unless stated otherwise	
Survey area	Route Length – 8681m Route Corridor width – 1000m	
Bathymetry		
Water depth along route	Maximum: 26.0m LAT; Minimum: 19.6m	

	Water depths along the proposed route corridor range between 26.4m at 26.0m at KP0.280 and 19.6m KP7.941.
Water depths within route corridor	Maximum: 26.4m LAT; Minimum: 18.5m LAT Water depths along the proposed route corridor range between 26.4m at approximately KP0.000 and 18.5m at KP8.232. The seabed shoals gently towards the east-north-east end of the proposed cable route. There is a small ridge at approximately KP5.133.
Seabed gradients and topography within route corridor	Bedforms are not imaged on the sonar or bathymetry records. However, photographs taken during the environmental survey clearly show ripples covering the majority of the seabed within the survey corridor. A series of natural minor troughs, predominantly trending north-west to south-east occur within the survey area. These are interpreted to be related to oceanographic processes and appear to cross the proposed cable route from approximately KP5.158 towards the end of the proposed cable route at KP8.681. Localised water depth variations are attributable to the relief and distribution of the troughs. Water depths along the proposed route range between 26.0m at KP0.280 and 19.6m KP7.941. The seabed shoals gently towards the east-north-east end of the proposed cable route. There is a small ridge at approximately KP5.133. Natural gradients along the proposed route are less than 1°. Maximum gradients of up to 7° are confined to flanks of the more prominent troughs. Three semi-circular features with 1m of positive relief, interpreted as being related to previous drilling activity, are imaged on bathymetry data. These are at the start of the proposed route between KP0.085 and KP0.168; at their minimum offset they are approximately 27m south-south-west. They appear to be within a 30m radius of each other with dimensions of 30m x 30m.
Seabed Features	
Seabed sediments along proposed route	Seabed sediments along the proposed cable route are expected to comprise fine to coarse SAND, with occasional areas of coarse SAND and CLAY with gravel and shell fragments.
Seabed sediments within route corridor	Seabed sediments along the proposed cable route corridor are expected to comprise fine to coarse SAND, with occasional areas of coarse SAND and CLAY with gravel and shell fragments.
Existing Infrastructure within the survey corridor and along the proposed route	The norned cable is imaged crossing the proposed cable route at KP2.313 trending north-north-west to south-south-east. Several magnetic contacts have been identified verifying the cable position.
Debris/obstructions along proposed route	Five contacts are within 10m of the proposed route, all of them interpreted as boulders. The closest to the proposed cable route occurs at KP4.479, 4.7m south-south-west of the proposed cable route and is 0.6m high.

Debris/obstructions within route corridor	Numerous objects, interpreted as boulders, occur within the proposed cable route corridor. The majority of the objects interpreted as boulders are located towards the north of the survey corridor area and coincide with areas of clay exposure. Numerous magnetic contacts have been detected within the corridor survey area. Several magnetic anomalies cluster near the start of the proposed route between KP0.020 and KP0.130. These are interpreted to be related to the three semi-circular features related to previous drilling activity. Other magnetic anomalies are not associated with any mapped seabed feature. These contacts may relate to buried debris items.
Shallow Soils	
Expected geology along route	The upper unit of fine to medium grained SAND generally thickens to the east. West of the route AC at KP 5.156 the unit is approximately 0.5 to 1m thick or absent/unmappably thin, east of this point the unit locally exceeds a thickness of 2m. Vibrocore logs show that the upper unit is sub-cropped by clay prone deposits from KP0 to KP 3.357, interpreted to be the infill of a broad channel. From KP 3.357 to the end of the route the upper unit is subcropped by fine SAND.
Potential Hazards	
Obstructions along route	Cobbles and boulders possible within the shallow geological sequence along the proposed route or anywhere within the survey corridor. Shallow gas 90m north of route from KP2.549 to KP2.651.

2 INTRODUCTION

2.1 PROJECT OVERVIEW

GEOxyz was contracted to do a geophysical route survey in the Dutch Sector, Block N5A along a proposed cable route corridor between the N5A Platform location and the Riffgat Windpark Transformet Station (see separate report ref LU0022H-553-RR-01). Multibeam echosounder (MBES), side scan sonar (SSS), magnetometer and sub-bottom profiler data were acquired along a 9km by 1km survey corridor.

Eleven environmental grab samples and five camera transects were acquired along the proposed route corridor.

Nine vibrocore samples were also acquired along the route and reported by Igeotest (Ref. 2).

Proposed cable route corridor location:

Table 1: N5A to Riffgat Cable Route

N5A to Riffgat Cable Route – ED50, UTM 31N, CM 3° E					
Proposed Cable Route Location	KP	Easting (m)	Northing (m)	Latitude	Longitude
Start of Route – N5A Platform Location	0.000	721 607.00	5 954 650.00	53° 41' 32.347" N	06° 21' 23.281" E
	5.156	726 730.61	5 954 070.44	53° 41' 05.716" N	06° 26' 00.580" E
	8.630	730 066.69	5 955 037.36	53° 41' 31.697" N	06° 29' 04.664" E
End of Route – Riffgat Windpark Transformer Station Location	8.681	730 081.00	5 954 988.00	53° 41' 30.080" N	06° 29' 05.312" E

The survey was carried out on the survey vessel Geo-Ocean III between the 1st and 15th May 2019.

The survey line plan is displayed in Figure 2.

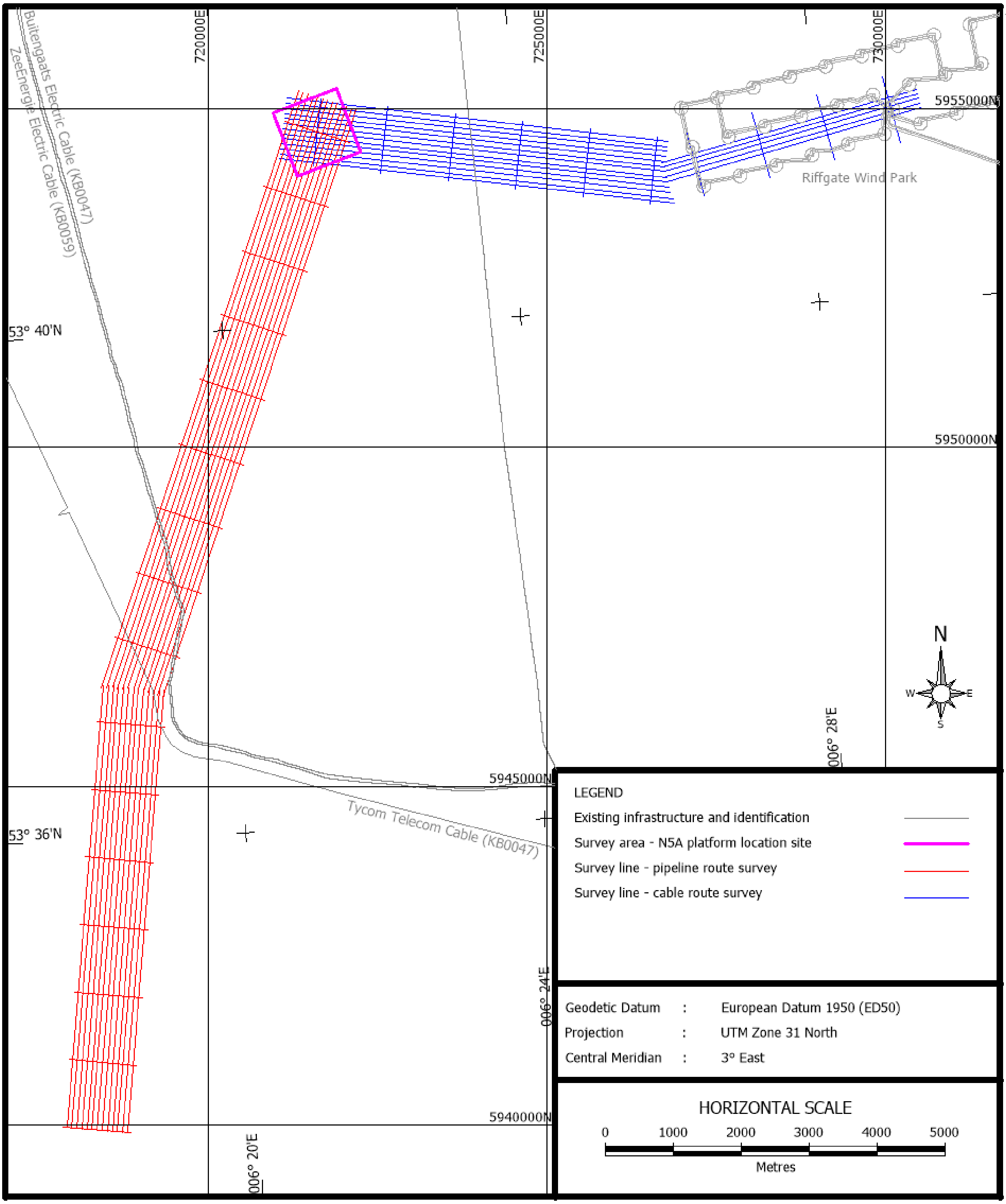


Figure 2: Survey line plan

2.2 SCOPE OF WORK

The objectives for the route survey are as follows:

- To complete all survey operations with no Health, Safety or Environmental incidents;
- To identify all geohazards and geological conditions relating to pipeline installation. This may include channelling, faulting and other geological features and variations that may be of significance;
- To identify any seabed obstructions;
- To establish water depths and seabed conditions;
- To investigate sub-seabed geological conditions to allow detailed soils classification, for assessment of trenching/cable lay conditions.

2.3 GEODETIC PARAMETERS

2.3.1 Horizontal Reference

Table 2: Geodetic parameters

Geodetic parameters	
Spheroid	International 1924
Semi-major axis	6378388.297
Semi-minor axis	6356911.946
Datum	European Datum 1950 (ED50)
Projection	Universal Transverse Mercator (UTM)
False Easting	500000.00
False Northing	0.00
Central Meridian	3° East
Central Scale Factor	0.9996
Latitude of Origin	0°
Grid Zone	31 North
Datum Transformation WGS84 – ED50	
dx	+ 89.5m
dy	+93.8m
dz	+123.1m
Rx	0.0
Ry	0.0
Rz	-0.156
Scale	-1.2ppm

2.3.2 Vertical Reference

All water depths have been reduced to LAT using the DTU15 model. MSL is 1.6m above LAT within the survey area.

3 DATA ACQUISITION PROCESSING & LIMITATIONS

3.1 MULTI-BEAM ECHO SOUNDER

Bathymetric data were acquired using a R2Sonic 2024 multibeam echosounder. Tidal reduction was carried out using the DTU15 model. Bathymetry data were reduced to Lowest Astronomical Tide (LAT). LAT is 1.6m below MSL within the survey area.

Water depths are quoted relative to Lowest Astronomical Tide (LAT) and are considered to be accurate to ±1% (approximately 0.3m). The multibeam data have been processed to a 0.5m x 0.5m bin size.

Data processing was carried out using QINSy and QIMERA. Data was recorded in QINSy as raw QPD files. Multibeam data were cleaned using a combination of basic filters applied to the entire data set and then individual QPDs were manually cleaned by deleting any further outliers within the data. Once cleaned, the QPDs were tidally corrected and further minor adjustments were made to visually improve the data within QIMERA. A final grid file was exported and contoured at a 0.5m contour interval and a Geo-Tiff produced for final presentation.

3.2 SIDE-SCAN SONAR

Side Scan Sonar data were acquired using an Edgetech 4200 with a frequency of 100kHz / 400 kHz operating at 150m/200m range.

Data were positioned using a Sonardyne Ranger 2 USBL system with the total accuracy of contacts affected by vessel positioning, the acoustic positioning of the towfish relative to the vessel and position of the contact relative to the towfish. For this survey position accuracy of the side scan sonar data set was generally between ±3-5m. MBES data has been used to improve the positioning of contacts picked from SSS data and features such as depressions, scars etc. are generally picked from the MBES data wherever possible.

Three main factors influence resolution in the along-track direction. These are horizontal beam width, tow speed and sonar range. These parameters are summarised in the table below. Across track resolution is determined by the sonar frequency. Although the higher frequency allows smaller objects to be detected it does limit range to ˜75m.

Sonar Range	150m/200m per channel
Horizontal Beam Width	100 kHz 1.5°
	400 kHz 0.4°
Vertical Beam Width	100 kHz/400 kHz 50°
Along Track Resolution	100 kHz 3.9m at 150m range
	400 kHz 1.1m at 150m range
Across Track Resolution	100 kHz 8cm
	400 kHz 2cm

The 100kHz data has been used to create the mosaic. Raw data were imported into Coda Survey Engine and the seabed position picked. Data were then scaled, and a time varying gain (TVG) and corrected navigation applied. Data were then slant range corrected and layered to create the most coherent mosaic possible. The mosaic has been exported at a resolution of 2 pixels per metre.

Target picking has generally taken place on the 400kHz data, however where coverage is less than 200% on the 400kHz data the 100kHz data were used. The same processing steps - seabed picked, scaling, TVG and corrected navigation have also been applied to the 400kHz data. Data were then examined on a line by line basis and seabed targets were picked – objects, linear debris, scars, depressions etc. Reviewed contact positions were reconciled between lines and target lists exported.

3.3 MAGNETOMETER

Magnetometer data were acquired using a Geometrics G882 magnetometer piggybacked 10m behind the side scan sonar.

Data were positioned using a Sonardyne Ranger 2 USBL system with the accuracy of contacts identified from magnetometer data being affected by vessel positioning and the acoustic positioning of the towfish. For this survey position accuracy of the magnetometer data was generally between ±3-5m (based on side scan sonar positioning).

Data were recorded as text files in QINSy and then graphed in Oasis Montaj where contacts of 10nT or greater were picked due to vessel associated noise from short layback in the shallow water and a target list is exported. The Magnetometer was flown at a height of 10-20m above the seabed meaning small contacts could potentially be missed. Due to the very low data density (the minimum line spacing was 37.5m) the reported position of magnetic contacts is the position of the anomaly along the survey line rather than an interpretation of the exact position of the potential magnetic contact. A contact could lie on either side of the survey line up to half the distance to the adjacent line, so if the line spacing was 50m the contact could lie up to 25m either side of the line. A magnetometer used this way is of limited usefulness but remains effective for confirming the positions of seabed infrastructure and highlighting approximate positions of large magnetic contacts.

3.4 SUB-BOTTOM PROFILER

Shallow soils conditions have been interpreted from pinger data collected within the survey area. Interpretation of the pinger dataset is limited to approximately 15ms TWT below seabed (12m ASV 1600m/s).

Estimated resolution for Pinger dataset is listed below.

Pinger

Vertical Resolution	0.1m (based on an estimated dominant frequency of 4kHz and an assumed constant velocity of 1600m/s). Direct observation of the records shows that a resolution of approximately 0.2m may be the practical limit.
Horizontal Resolution	0.6m based on 250 millisecond trigger rate. 4m Fresnel zone at 20ms (based on an estimated dominant frequency of 4kHz and an assumed constant velocity of 1600m/s).

Pinger data were recorded in Coda acquisition software in cod file format. The seabed was picked, data were scaled, a TVG applied and either heave compensation or a swell filter applied. Data were then exported as a processed segy file and imported into the Kingdom 2016 software where interpretation was carried out.

Time to depth conversion has been carried out using an assumed constant seismic velocity of 1600m/s.

Lithological descriptions are interpreted from seismic character and geotechnical information (Refs. 2 and 3).

Segy data were loaded into a kingdom workstation once processing had been completed and basic QC of the data took place. Seabed position was checked against time converted MBES xyz data. Key horizons were then picked, and all data was checked for anomalies and variations by iterative visual assessment.

4 DETAILED RESULTS

4.1 BATHYMETRY

Bathymetry data were acquired using an R2Sonic 2024 multi-beam echo sounder and have been reduced to LAT. LAT is 1.6m below MSL along the route corridor. Bathymetry data were gridded at a 0.5 x 0.5m cell size. A bathymetry profile through the proposed survey route is included as Figure 3.

A series of natural minor troughs, predominantly trending north-west to south-east, occur within the survey area. These are interpreted to be related to tidal/current processes and appear to cross the proposed cable route from approximately KP5.158 towards the end of the proposed cable route at KP8.681.

Localised water depth variations are attributable to the relief and distribution of the identified troughs. Water depths along the proposed route range between 26.0m at KP0.280 and 19.6m KP7.941. The seabed shoals gently towards the east-north-east end of the proposed cable route. A small ridge located at approximately KP5.133.

Natural gradients along the proposed route are less the 1°. Maximum gradients of up to 7° are confined to the flanks of the more prominent troughs.

Three semi-circular features with 1m of positive relief, interpreted as being related to previous drilling activity, are imaged in the bathymetry data. These are positioned at the start of the proposed route between KP0.085 and KP0.168; at their minimum offset from the route they are approximately 27m south-south-west. They are positioned within a 30m radius and have average dimensions of 30m x 30m.

The Norned cable is observed crossing the proposed cable route at KP 2.313 trending north-north-west to south-south-east.

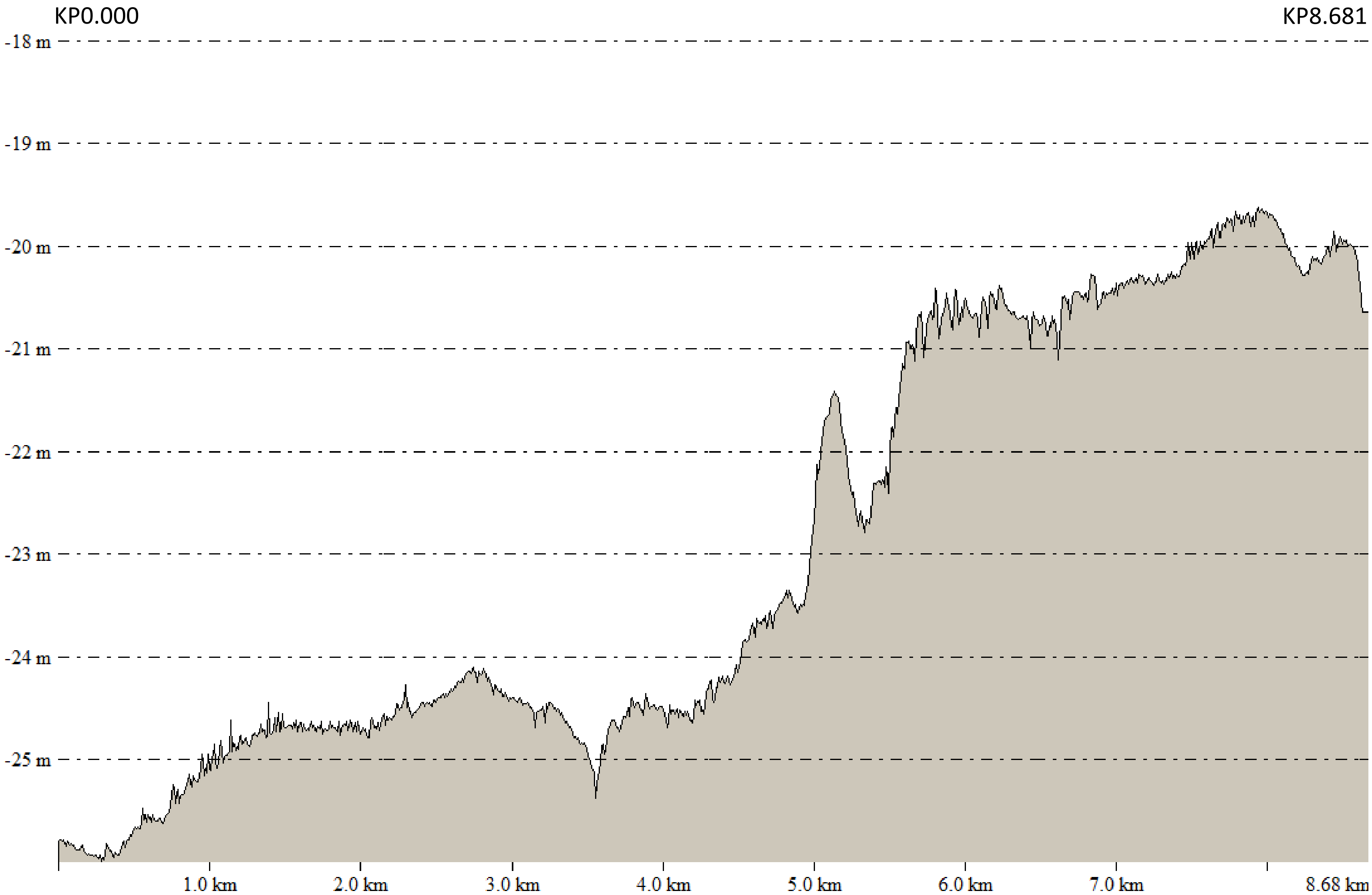


Figure 3: Bathymetric profile along the proposed cable route N5A Platform to Riffgat

4.2 SEABED FEATURES

Side scan sonar data were acquired with an Edgetech 4200 system operating at 100kHz/400kHz (150m/200m per channel range). This was supplemented by swathe bathymetry data gridded to a 0.5m bin size.

4.2.1 Seabed Sediments

Seabed sediments along the proposed cable route corridor are expected to comprise fine to coarse SAND, with occasional areas of coarse SAND and CLAY with gravel and shell fragments. Seabed sediment types examples are included as Figures 4 and 5 below.

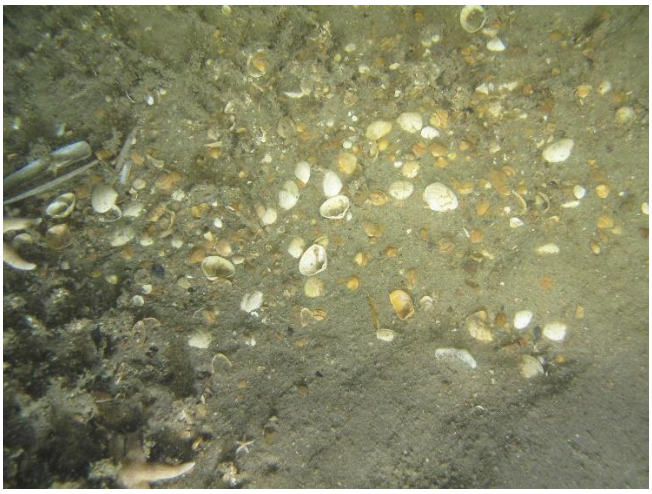



Figure 4: Environmental Images illustrating seabed sediment types within the proposed cable route N5A Platform to Riffgat corridor. (Left Photo - GRAB_C_1. Right Photo – GRAB_C_8)


Figure 5: Environmental Images illustrating bedforms covering the seabed within the cable route N5A Platform to Riffgat corridor. (Left Photo - GRAB_C_6. Right Photo – GRAB_C_7)

4.2.2 Seabed Morphology

Bedforms are not imaged in the sonar or bathymetry records. However, photographs taken along the proposed route corridor as part of the environment survey clearly show ripples covering the majority of the seabed within the survey corridor area (ref. Figure 5).

The seabed along the proposed pipeline route corridor varies very slightly shoaling towards the end of the route, with minimum and maximum water depths along the route of 19.6m LAT and 26.0m LAT respectively.

4.2.3 Seabed Obstructions

There are numerous objects interpreted as boulders within the proposed pipeline route corridor. These have been plotted and illustrated on Panel 2 of alignment charts. Most of the objects, interpreted as boulders occur towards the north of the survey corridor in an area coinciding with areas of clay exposure.

Five contacts occur within 10m of the proposed route, all of them interpreted as boulders. The closest to the proposed cable route occurs at KP4.479, 4.7m south-south-west of the proposed cable route and is 0.6m high. Sonar contacts within 200m of the proposed cable route are listed in Table 4.

Numerous magnetic contacts have been detected within the corridor survey area. Several magnetic anomalies cluster near the start of the proposed route between KP0.020 and KP0.130. Three semi-circular features with 1m of positive relief, interpreted as being related to previous drilling activity, are imaged in the bathymetry data (ref. Figure 6).

Several magnetic contacts are aligned, trending north-north-west to south-south-east, within the survey corridor area crossing the proposed cable route at approximately KP2.313. These are associated with the existing Norned cable. A sonar data example illustrating the position of the Norned cable is included as Figure 7.

Other recorded magnetic anomalies are not associated with any interpreted seabed feature. They are possibly associated with buried objects.

Magnetic contacts within 200m of the proposed pipeline route are listed in the Table 5.

Table 3: Side Scan Sonar Contact Listing

Side Scan Sonar Contact List					
Description	KP	DCC (m)	Easting (m)	Northing (m)	Height (m)
Object	-0.194	-41.1	721 419.2	5 954 712.6	0.7
Object	-0.184	142.5	721 408.5	5 954 529.1	1.3
Object	-0.159	-80.5	721 458.1	5 954 747.9	0.9
Object	-0.054	-10.3	721 555.0	5 954 666.2	0.8
Object	0.020	93.9	721 616.0	5 954 554.5	0.6
Object	0.032	-148.0	721 655.2	5 954 793.5	0.7
Object	0.033	128.0	721 625.0	5 954 519.2	0.7
Object	0.054	80.0	721 652.1	5 954 564.4	0.6
Object	0.145	38.2	721 746.8	5 954 595.7	0.6
Object	0.162	14.9	721 766.6	5 954 616.9	0.8
Object	0.169	135.2	721 759.4	5 954 496.7	0.6
Object	0.183	-25.5	721 791.4	5 954 654.8	0.5
Object	0.189	199.4	721 772.5	5 954 430.6	0.6
Object	0.208	-15.3	721 815.4	5 954 641.9	0.6
Object	0.224	36.9	721 825.4	5 954 588.2	0.5
Object	0.227	29.6	721 829.4	5 954 595.1	0.6
Object	0.250	27.9	721 852.0	5 954 594.2	0.6

Object	0.252	-5.5	721 858.2	5 954 627.1	0.6
Object	0.266	-81.4	721 880.7	5 954 700.9	0.6
Object	0.266	186.5	721 850.6	5 954 434.7	0.6
Object	0.297	47.3	721 896.8	5 954 569.6	0.7
Object	0.311	-98.3	721 927.0	5 954 712.8	0.5
Object	0.344	74.7	721 940.2	5 954 537.2	0.7
Object	0.430	75.1	722 026.1	5 954 527.0	0.7
Object	0.452	168.9	722 037.4	5 954 431.4	0.9
Object	0.469	65.0	722 065.6	5 954 532.7	0.5
Object	0.475	57.8	722 072.3	5 954 539.2	0.5
Object	0.509	185.6	722 091.6	5 954 408.4	0.8
Object	0.535	95.9	722 127.9	5 954 494.6	0.5
Object	0.558	-59.3	722 168.5	5 954 646.2	0.5
Object	0.559	-114.7	722 175.0	5 954 701.1	0.7
Object	0.632	-189.2	722 256.4	5 954 767.0	0.8
Object	0.658	21.2	722 258.5	5 954 555.0	0.6
Object	0.658	-45.2	722 266.1	5 954 620.9	0.5
Object	0.667	28.0	722 266.7	5 954 547.2	0.6
Object	0.709	-135.5	722 326.4	5 954 705.0	1.1
Object	0.755	-48.7	722 362.9	5 954 613.5	0.6
Object	0.784	-184.7	722 407.2	5 954 745.4	0.6
Object	1.646	-34.4	723 246.4	5 954 499.2	0.8
Object	2.258	-97.5	723 862.1	5 954 493.0	1
Object	3.046	-104.2	724 644.9	5 954 411.2	0.5
Object	3.129	-135.6	724 731.1	5 954 433.1	0.7
Object	3.162	-156.9	724 766.8	5 954 450.5	0.6
Object	3.174	-157.3	724 778.6	5 954 449.5	0.6
Object	3.185	-57.7	724 778.7	5 954 349.3	0.6
Object	3.350	-55.7	724 942.4	5 954 328.7	0.7
Object	3.390	-125.8	724 989.4	5 954 394.0	0.6
Object	3.412	-108.9	725 009.8	5 954 374.7	0.7
Object	3.541	10.3	725 124.3	5 954 241.8	0.6
Object	3.551	13.4	725 134.4	5 954 237.5	0.6
Object	3.557	-28.6	725 144.7	5 954 278.6	0.6
Object	3.564	-17.2	725 150.	5 954 266.5	0.5
Object	3.565	-28.3	725 152.2	5 954 277.5	0.5
Object	3.597	20.7	725 178.6	5 954 225.2	0.5
Object	3.643	-181.5	725 246.9	5 954 421.	0.7
Object	3.674	114.7	725 244.5	5 954 123.2	0.5
Object	3.700	188.4	725 262.4	5 954 046.9	0.6
Object	3.704	98.2	725 276.3	5 954 136.2	0.5
Object	3.704	-6.7	725 288.5	5 954 240.3	0.6
Object	3.721	170.9	725 285.5	5 954 061.9	0.9
Object	3.745	7.3	725 327.3	5 954 221.9	0.7
Object	3.755	12.4	725 336.5	5 954 215.6	0.8
Object	3.755	-25.0	725 341.3	5 954 252.8	0.6
Object	3.766	22.7	725 346.4	5 954 204.1	0.5
Object	3.800	193.4	725 361.6	5 954 030.7	0.7
Object	3.803	-16.0	725 387.3	5 954 238.5	0.5
Object	3.831	-129.6	725 428.3	5 954 348.2	0.6
Object	3.933	131.0	725 500.7	5 954 077.7	0.6

Object	4.067	-21.7	725 650.5	5 954 214.5	0.5
Object	4.077	-122.5	725 671.5	5 954 313.5	0.6
Object	4.079	-23.1	725 663.1	5 954 214.4	0.6
Object	4.230	-190.9	725 831.4	5 954 364.2	0.5
Object	4.368	-164.6	725 965.9	5 954 322.6	0.7
Object	4.479	44.1	726 052.2	5 954 102.8	0.5
Object	4.479	4.7	726 057.4	5 954 141.9	0.6
Object	4.531	-50.3	726 114.5	5 954 190.8	0.6
Object	4.531	15.2	726 107.6	5 954 125.6	0.7
Object	4.545	29.0	726 119.6	5 954 110.4	0.6
Object	4.594	-16.9	726 173.3	5 954 150.5	0.5
Object	4.805	-36.9	726 385.9	5 954 146.6	0.9
Object	4.925	-8.4	726 502.	5 954 104.7	0.8
Object	4.930	-11.7	726 506.9	5 954 107.5	0.7
Object	5.349	-161.5	726 871.	5 954 279.2	0.6
Object	5.405	-39.6	726 958.2	5 954 177.6	0.6
Object	5.434	-28.8	726 989.5	5 954 175.5	0.7
Object	5.493	-26.6	727 046.9	5 954 189.8	0.5
Object	5.602	-195.7	727 104.2	5 954 382.5	1.1
Object	8.294	-166.9	729 697.5	5 955 104.1	0.6
Object	8.340	-50.0	729 774.8	5 955 004.8	0.7
Object	8.360	-144.4	729 767.4	5 955 101.0	0.5
Object	8.371	-95.1	729 791.7	5 955 056.7	0.9
Object	8.600	-169.5	729 990.5	5 955 191.8	0.6

Table 4: Magnetometer Contact Listing

Magnetometer Contact List						
Description	KP	DCC (m)	Easting (m)	Northing (m)	Strength (nT)	Comments
Magnetic Contact	-0.177	53.8	721 424.9	5 954 616.5	285	
Magnetic Contact	-0.048	-107.8	721 571.7	5 954 762.5	18	
Magnetic Contact	0.024	51.1	721 625.3	5 954 596.5	53	Correlated to semi-circular features related to previous drilling activity (ref. Figure 6)
Magnetic Contact	0.054	20.1	721 658.0	5 954 624.0	45	
Magnetic Contact	0.054	94.5	721 650.5	5 954 550.0	376	
Magnetic Contact	0.057	54.9	721 657.8	5 954 589.0	358	
Magnetic Contact	0.063	-4.7	721 670.5	5 954 647.5	27	
Magnetic Contact	0.068	66.8	721 666.7	5 954 576.0	1100	
Magnetic Contact	0.075	80.1	721 672.2	5 954 562.0	2733	
Magnetic Contact	0.090	111.6	721 683.6	5 954 529.0	252	
Magnetic Contact	0.090	50.2	721 691.2	5 954 590.0	360	
Magnetic Contact	0.100	186.9	721 685.7	5 954 453.0	110	
Magnetic Contact	0.111	134.4	721 702.2	5 954 504.0	58	
Magnetic Contact	0.121	169.5	721 708.2	5 954 468.0	119	
Magnetic Contact	1.268	83.0	722 858.1	5 954 425.0	43	
Magnetic Contact	2.313	1.0	723 905.1	5 954 389.0	15	
Magnetic Contact	2.473	-150.9	724 080.9	5 954 522.0	40	
Magnetic Contact	2.591	-9.3	724 182.6	5 954 368.0	43	
Magnetic Contact	2.597	-151.4	724 205.0	5 954 508.5	31	
Magnetic Contact	2.634	5.5	724 223.6	5 954 348.5	27	
Magnetic Contact	2.821	0.9	724 410.1	5 954 332.0	36	
Magnetic Contact	2.831	-7.3	724 420.9	5 954 339.0	38	
Magnetic Contact	2.862	77.8	724 442.2	5 954 251.0	18	
Magnetic Contact	2.877	147.1	724 449.1	5 954 180.5	16	
Magnetic Contact	2.925	0.8	724 512.9	5 954 320.5	12	
Magnetic Contact	5.627	0.4	727 182.4	5 954 201.0	25	
Magnetic Contact	7.532	-62.2	728 994.9	5 954 791.5	14	
Magnetic Contact	8.195	-119.9	729 615.7	5 955 031.5	26	

Table 5 - Summary of Grab samples in the N5A Platform to Riffgat Cable Route Area

Station	Type	Easting	Northing
GRAB_P_0	EBS/HAS	721 617.9	5 954 452
GRAB_C_0	EBS/HAS	721 607.0	5 954 650
GRAB_C_1	EBS/HAS	722 600.7	5 954 538
GRAB_C_2	EBS/HAS	723 594.3	5 954 425
GRAB_C_3	EBS/HAS	724 588.0	5 954 313
GRAB_C_4	EBS/HAS	725 581.7	5 954 200
GRAB_C_5	EBS/HAS	726 575.3	5 954 088
GRAB_C_6	EBS/HAS	727 353.0	5 954 244
GRAB_C_7	EBS/HAS	728 146.1	5 954 478
GRAB_C_8	EBS/HAS	729 107.9	5 954 759
GRAB_C3_2	EBS/HAS	725 335.2	5 953 740

Table 6 - Summary of Completed Camera Transects

Geodetics: ED50 UTM31N 3°E							
Transect		**Date and Time**	**Depth (m)**	**Easting**	**Northing**	**No. Stills**	**Video footage (mm:ss)**
Grab P_0	SOL	02/05/2019 17:15:11	30	721647	5954430	27	07:13
	EOL	02/05/2019 17:22:21	31	721591	5954476		
North Transect 3	SOL	11/05.2019 02:04:48	28.9	721902	5954407	50	12:29
	EOL	11/05/2019 02:17:13	28.8	721802	5954550		
North Transect 3	SOL	11/05.2019 02:04:48	28.9	721902	5954407	50	12:29
	EOL	11/05/2019 02:17:13	28.8	721802	5954550		
N5a Transect 1	SOL	11/05/2019 01:38:05	28.71	721585	5954588	35	08:37
	EOL	11/05/2019 01:46:38	28.63	721626	5954708		
N5a Transect 2	SOL	11/05/2019 01:16:28	28.44	721668	5954631	39	09:13
	EOL	11/05/2019 01:25:35	28.64	721544	5954667		
Grab_C3_2	SOL	14/05/2019 20:46:00	24.97	725366	5953610	37	12:36
	EOL	14/05/2019 20:58:53	24.5	725326	5953785		

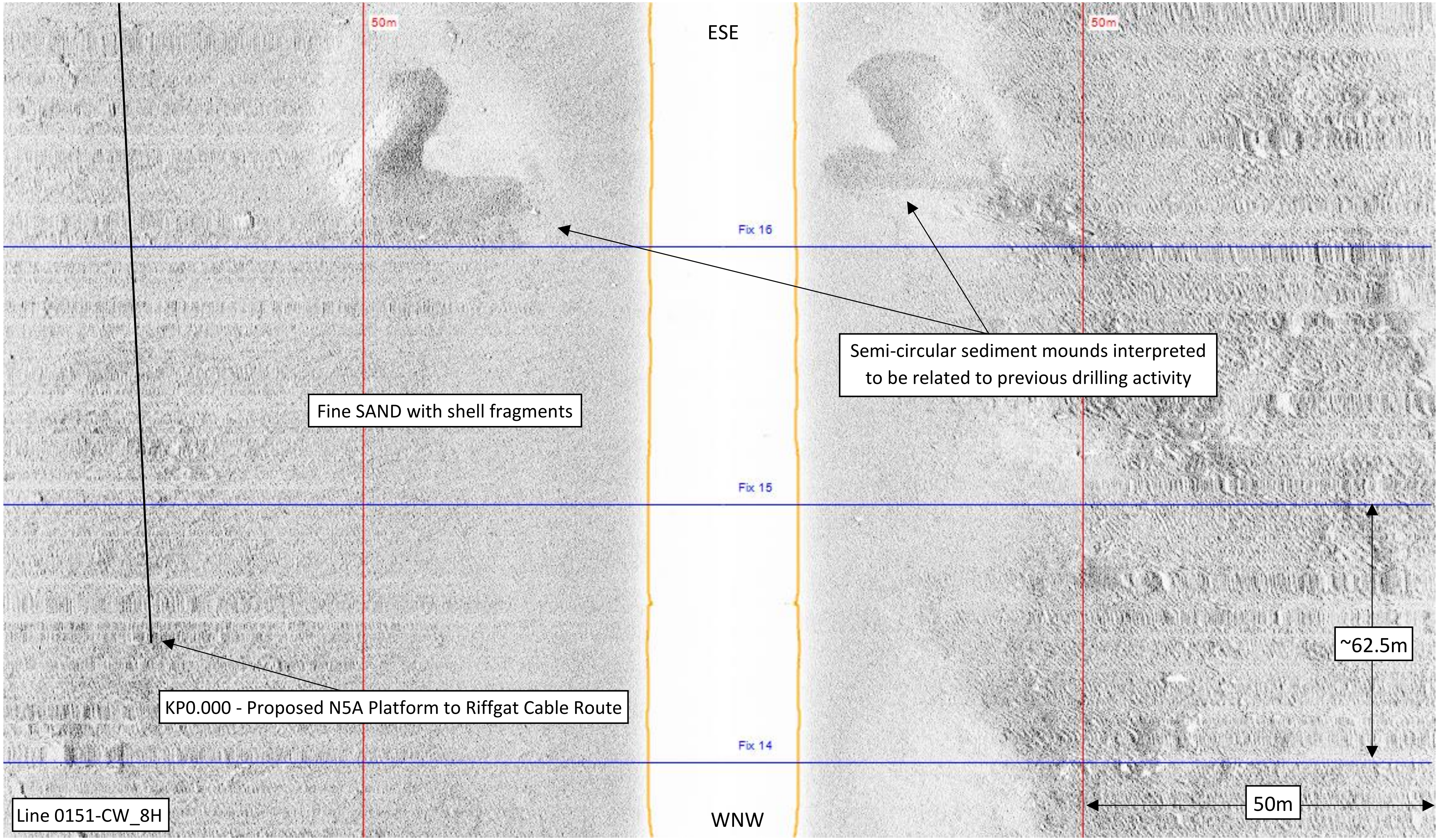


Figure 6. Side scan sonar data example illustrating seabed sediments at KP0.000 (start of route) of the Proposed N5A Platform to Riffgat cable route

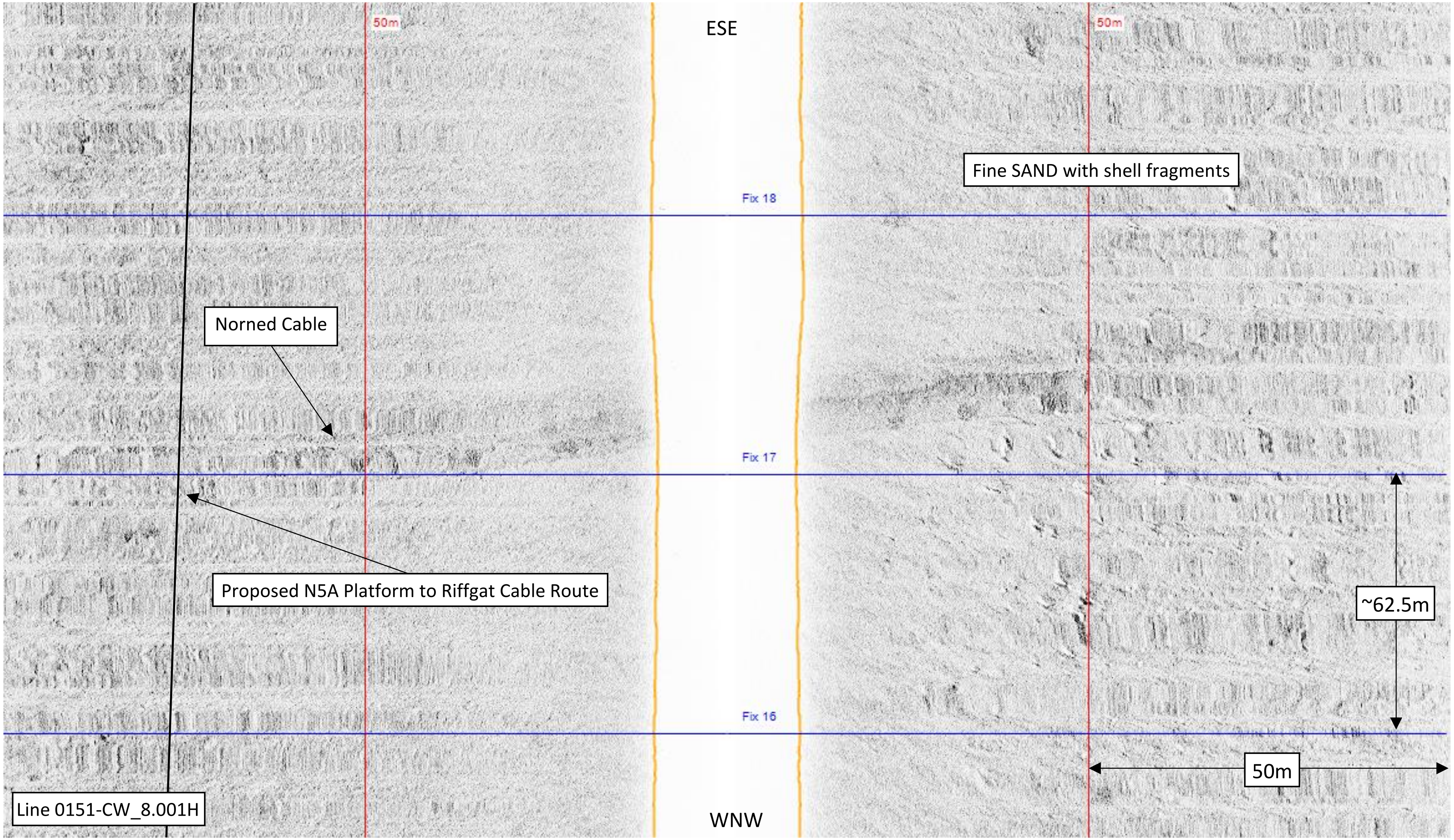


Figure 7. Side scan sonar data example illustrating Norned cable crossing with the Proposed N5A Platform to Riffgat cable route

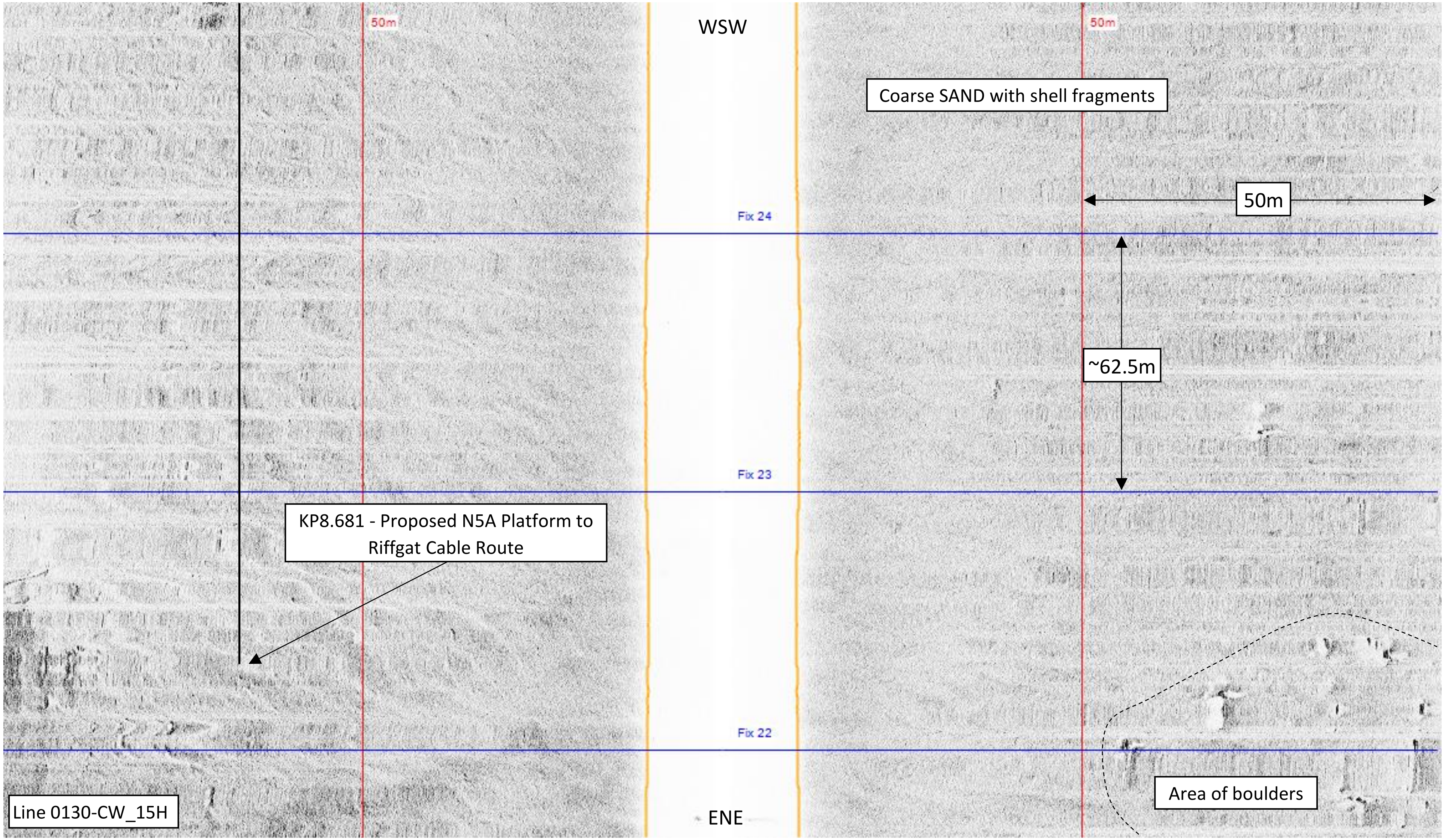


Figure 8. Side scan sonar data example illustrating seabed sediments at KP8.681 (end of route) of the Proposed N5A Platform to Riffgat cable route

4.3 SHALLOW SOILS

Interpretation of the shallow soils is based upon sub-bottom profiler dataset in conjunction with borehole and route-specific vibrocore data (References 2 and 3). Pinger data examples illustrating shallow soils along the proposed route are included as Figures 9 and 10.

Appendix A shows route specific core logs (Ref. 2).

4.3.1 Surficial SAND (Seabed-H01, absent-3m BSB)

This unit of fine to medium grained SAND generally thickens to the east. West of the route AC at KP 5.156 the unit is approximately 0.5 to 1m thick or absent/unmappably thin, east of this point the unit locally exceeds a thickness of 2m. The following table shows where the unit is absent (or too thin to map):

Table 7: Absences of surficial SAND

KP start absence	KP end absence
0.076	1.203
2.629	2.877
3.062	3.243
3.553	3.883
4.007	4.042
4.156	4.996
5.318	5.464

4.3.2 Sub-crop (Seabed/H01 -, 0->10m BSB)

Vibrocore logs show that the mapped unit is sub-cropped by clay prone deposits from KP0 to KP 3.357, interpreted to be the infill of a broad channel. From KP 3.357 to the end of the route the mapped unit is subcropped by fine SAND.

Table 8: Summary of vibrocore locations

No.	Vibrocore ID	Easting (m)	Northing (m)	Penetration (m)	Recovery (m)
1	VC_C_1	722 602.8	5 954 534.4	3.2	3.2
2	VC_C_2	723 596.5	5 954 423.7	3.0	3.0
3	VC_C_3	724 581.3	5 954 314.2	2.8	2.5
4	VC_C_3BIS	724 581.2	5 954 315.8	2.4	2.1
5	VC_C_4	725 574.1	5 954 201.4	6.0	5.5
6	VC_C_5	726 573.0	5 954 087.2	5.8	5.5
7	VC_C_6	727 343.7	5 954 245.0	5.7	5.6
8	VC_C_7	728 143.0	5 954 481.2	5.3	5.3
9	VC_C_8	729 111.9	5 954 761.2	5.6	5.6

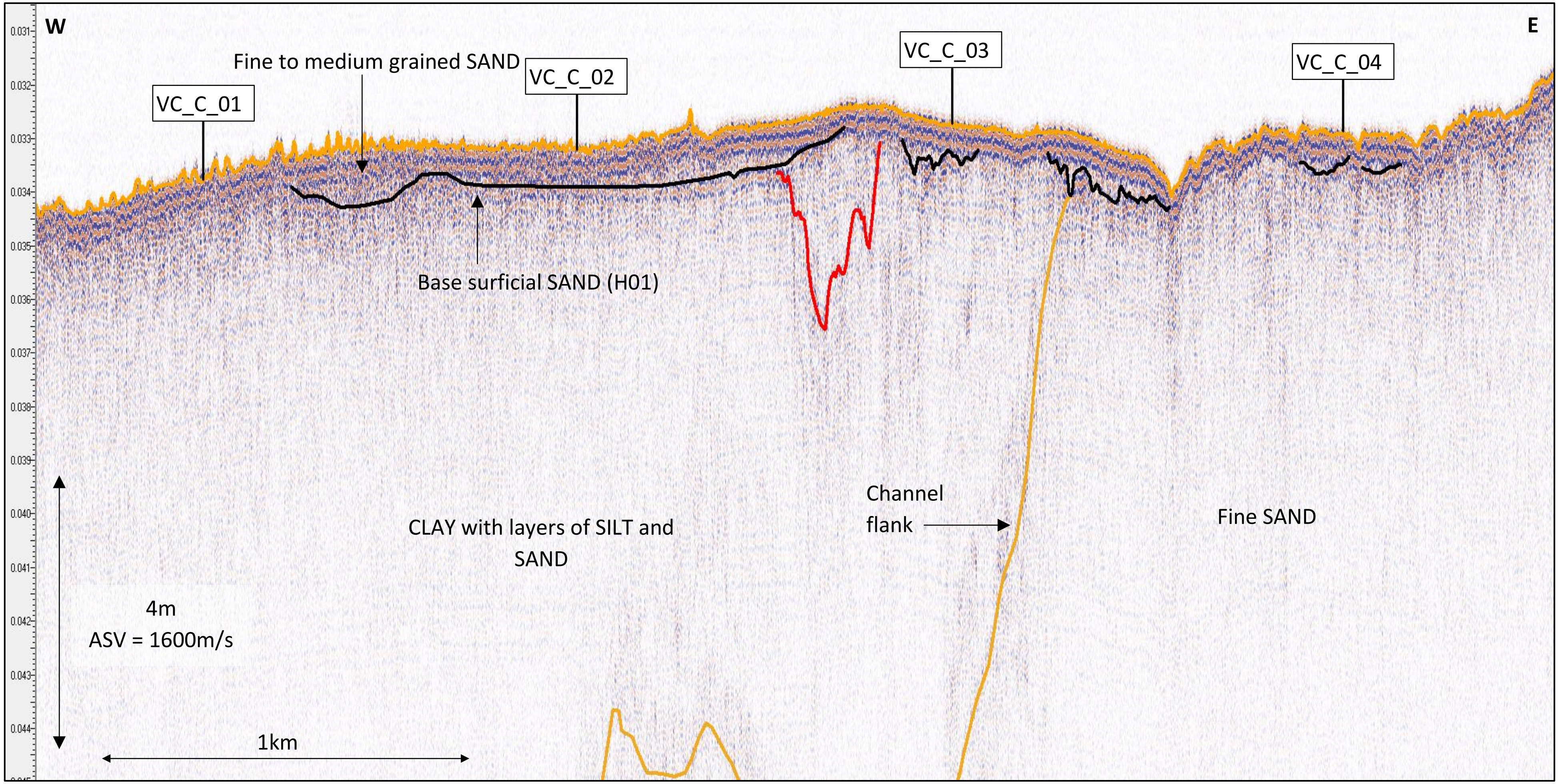


Figure 9: SBP data example at the start of the Proposed Route, Line CW_7_PROC

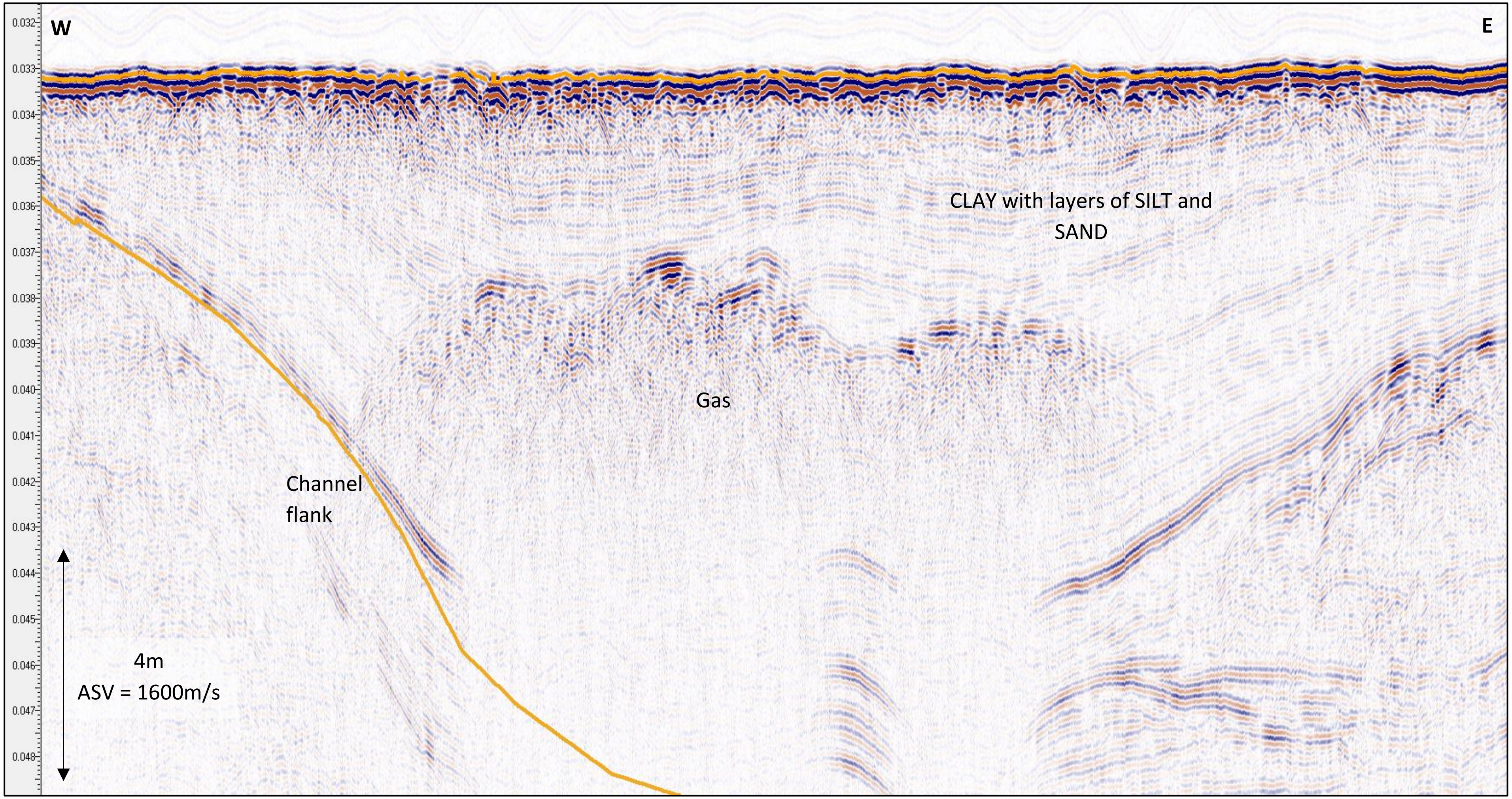


Figure 10: SBP data example, shallow gas, Line CW_6_PROC

APPENDIX A – PRELIMINARY VC RESULTS

FIELD VERSION

POINT: VC_C_1
COORDINATES (UTM)
N 5954534.42 m
E 722602.76 m
Water depth 27.00 m

START DATE: 10/5/19
FINISH DATE: 1/10/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND · CLAY · SILT · SANDST

C.BARREL/C.SIZE (mm): 106

DEPTH (m BGL)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	REMARKS
	0.00- 0.16: Very dark gray (2.5Y 3/1) medium to coarse SAND with rare fine gravel and frequent shell fragments (some of them medium gravel sized). Clear but not sustained effervescence from HCl.			
	0.16- 0.89: Very closely fissured black (5Y 2.5/1) CLAY with occasional fine sand pockets. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.	S-3		
	0.89- 1.05: Very dark grayish brown (2.5Y 3/2) slightly sandy SILT with occasional clay pockets.		VC_C_1.3	
1.00	1.05- 1.07: Very closely fissured black (5Y 2.5/1) CLAY. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.			
	1.07- 1.12: Black (5Y 2.5/1) fine SAND. Clear but not sustained effervescence from HCl.			
	1.12- 2.30: Very closely fissured black (5Y 2.5/1) CLAY with frequent fine sand pockets. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.		VC_C_1.2	
2.00		S-2		
	2.30- 3.20: Very dark grayish brown (2.5Y 3/2) silty fine SAND with frequent clay pockets and milimetrical to centimetrical clay layers. Clear but not sustained effervescence from HCl, clay no sustained effervescence from HCl.		VC_C_1.1	
3.00		S-1		

Bottom at 3.20 m

Undrained Shear Strength Su (kPa)
⊗ TV   □ PP
50 100 150 200

DETAILED PHOTOS

FIELD VERSION

POINT: VC_C_2
COORDINATES (UTM)
N 5954423.75 m
E 723596.51 m
Water depth 27.30 m

START DATE: 10/5/19
FINISH DATE: 10/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND CLAY

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV □ PP 50 100 150 200	REMARKS
0.00–0.50	SAND	106	0.00- 0.50: Light olive brown (2.5Y 5/4) fine to medium SAND with rare amorphous organic matter blackish zones and occasional shell fragments and polychaetes (specifically Lanice conchilega). Clear but not sustained effervescence from HCl. · From 0.43m to 0.50m: fine to medium SAND with fine to medium gravel with frequent shell fragments		VC_C_2.3		
0.50–1.10	CLAY		0.50- 1.10: Very closely fissured black (5Y 2.5/1) CLAY. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.	S-3 (1.00)			
1.10–3.00	CLAY		1.10- 3.00: Very closely fissured black (5Y 2.5/1) CLAY with rare brownish pockets. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.	S-2 (2.00) S-1 (3.00)	VC_C_2.2 VC_C_2.1		

Bottom at 3.00 m

DETAILED PHOTOS



FIELD VERSION

POINT: VC_C_3
COORDINATES (UTM)
N 5954314.25 m
E 724581.29 m
Water depth 27.00 m

START DATE: 10/5/19
FINISH DATE: 10/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

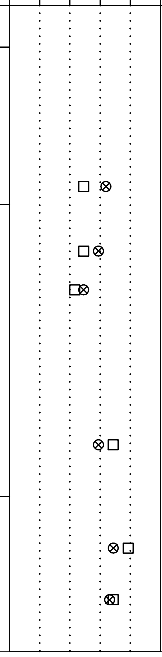
REMARKS:

LEGEND

SAND CLAY

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV □ PP 50 100 150 200	REMARKS
			0.00- 0.38: Olive brown (2.5Y 4/3) fine to medium SAND with frequent amorphous organic matter and occasional shell fragments. Clear but not sustained effervescence from HCl.		VC_C_3.3		
			0.38- 2.50: Very closely fissured black (5Y 2.5/1) CLAY. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.	S-3	VC_C_3.2		
1.00		106		S-2	VC_C_3.1		
2.00				S-1			

Bottom at 2.50 m



DETAILED PHOTOS

FIELD VERSION

POINT: VC_C_3Bis
COORDINATES (UTM)
N 5954315.81 m
E 724581.23 m
Water depth 27.00 m

START DATE: 10/5/19
FINISH DATE: 10/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND CLAY

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV ◻ PP 50 100 150 200	REMARKS
			0.00- 0.35: Olive brown (2.5Y 4/3) fine to medium SAND with frequent amorphous organic matter, occasional shell fragments and polychaetes. (specifically Lanice conchilega). Clear but not sustained effervescence from HCl.		VC_C_3Bis.2		
1.00		106	0.35- 2.10: Very closely fissured black (5Y 2.5/1) CLAY. No sustained effervescence from HCl. The fissures are horizontal and unpolished with a sustained effervescence from HCl.	S-2	VC_C_3Bis.1		
2.00				S-1			

Bottom at 2.10 m

DETAILED PHOTOS

FIELD VERSION

POINT: VC_C_4
COORDINATES (UTM)
N 5954201.36 m
E 725574.08 m
Water depth 27.00 m

START DATE: 10/5/19
FINISH DATE: 10/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV ☐ PP (50 100 150 200)	REMARKS
		106	0.00- 0.55: Black (5Y 2.5/1) fine SAND with rare fine to medium gravel and occasional shell fragments. No sustained effervescence from HCl.	S-6	VC_C_4.6		
1.00			0.55- 1.50: Black (5Y 2.5/1) fine SAND with rare fine gravel. No sustained effervescence from HCl. · From 1.00m to 1.10m: Dark gray (5Y 4/1) medium to coarse SAND.	S-5	VC_C_4.5		
2.00 3.00 4.00 5.00			1.50- 5.50: Dark olive gray (5Y 3/2) fine SAND with rare fine gravel, rare medium sand pockets and occasional amorphous organic matter blackish zones. No sustained effervescence from HCl.	S-4 S-3 S-2 S-1	VC_C_4.4 VC_C_4.3 VC_C_4.2 VC_C_4.1		

Bottom at 5.50 m

DETAILED PHOTOS






FIELD VERSION

POINT: VC_C_5
COORDINATES (UTM)
N 5954087.23 m
E 726572.99 m
Water depth 24.50 m

START DATE: 10/5/19
FINISH DATE: 10/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV ☐ PP 50 100 150 200	REMARKS
			0.00- 0.32: Light olive brown (2.5Y 5/4) medium SAND with rare fine gravel, frequent amorphous organic matter blackish zones, and occasional shell fragments. No sustained effervescence from HCl.		VC_C_5.6		
			0.32- 0.50: Very dark gray (5Y 3/1) fine SAND with rare clay pockets and milimetrical layers, with occasional amorphous organic matter and rare shell fragments. No sustained effervescence from HCl.				
			0.50- 1.00: Olive gray (5Y 4/2) fine SAND with occasional fine to medium gravel, rare clay pockets and rare fibrous wood fragmetns. No sustained effervescence from HCl. ·From 0.84m to 1.00m: medium SAND.	S-6	VC_C_5.5		
1.00		106	1.00- 5.50: Very dark gray (5Y 3/1) fine SAND with rare clay pockets and occasional amorphous organic matter blackish zones. No sustained effervescence from HCl. · From 2.05m to 2.45m: frequent amorphous organic matter milimetrical layers. · From 3.05m to 4.16m: frequent amorphous organic matter milimetrical layers and micas.	S-5			
2.00					VC_C_5.4		
				S-4	VC_C_5.3		
3.00				S-3			
4.00					VC_C_5.2		
				S-2			
5.00					VC_C_5.1		
				S-1			

Bottom at 5.50 m

DETAILED PHOTOS






FIELD VERSION

POINT: VC_C_6
COORDINATES (UTM)
N 5954245.05 m
E 727343.67 m
Water depth 23.30 m

START DATE: 9/5/19
FINISH DATE: 9/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND SANDCL

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV ☐ PP 50 100 150 200	REMARKS
			0.00- 0.21: Dark grayish brown (2.5 4/2) fine to medium SAND with rare shell fragments. Clear but not sustained effervescence from HCl.				
			0.21- 0.60: Dark gray (2.5Y 4/1) fine to medium SAND with rare clay pockets and rare shell fragments. Suistained effervescence from HCl.		VC_C_6.6		
			0.60- 1.04: Olive gray (5Y 5/2) fine SAND thickly laminated with dark olive gray (5Y 3/2) silty clay with rare blackish amorphous organic matter pockets an rare shell fragments. Sustained effervescence from HCl.	S-6	VC_C_6.5		
1.00			1.04- 2.06: Grayish brown (2.5Y 5/2) fine to medium SAND with rare clay pockets, rare fibrous wood fragments and rare shell fragments. No sustained effervescence from HCl. · From 1.60m to 2.06m: rare fine gravel.	S-5			
2.00			2.06- 2.39: Grayish brown (2.5Y 5/2) fine to medium SAND with occasional coarse sand and occasional fine to coarse gravel. No sustained effervescence from HCl.		VC_C_6.4		
		106	2.39- 3.10: Grayish brown (2.5Y 5/2) fine to medium SAND with rare amorphous organic matter. No sustained effervescence from HCl. · From 2.90m to 3.10m: progressively size increasing to medium and coarse sand.	S-4			
3.00			3.10- 4.84: Grayish brown (2.5Y 5/2) medium to coarse SAND with occasional fine sand, rare fine gravel and rare amorphous organic matter blackish zones. No sustained effervescence from HCl. · From 4.00m to 4.40m: mainly coarse SAND with rare fine to medium gravel.	S-3 S-2	VC_C_6.3 VC_C_6.2		
4.00							
5.00			4.84- 5.33: Dark olive gray (5Y 3/2) fine to medium SAND. No sustained effervescence from HCl.				
			5.33- 5.60: Thickly laminated olive gray (5Y 4/2) silty fine SAND and fine SAND with occasional amorphous organic matter milimetrical layers. No sustained effervescence from HCl.	S*1	VC_C_6.1		

Bottom at 5.60 m

DETAILED PHOTOS






FIELD VERSION

POINT: VC_C_7
COORDINATES (UTM)
N 5954481.18 m
E 728142.96 m
Water depth 23.10 m

START DATE: 9/5/19
FINISH DATE: 9/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND

DEPTH (m BGL)	GRAPHIC LOG	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests	Undrained Shear Strength Su (kPa) ⊗ TV Pocket Torvane □ PP Pocket Penetrometer 50 100 150 200	REMARKS
			0.00- 0.27: Dark olive gray (5Y 3/2) fine SAND with rare amorphous organic matter blackish pockets and occasional shell fragments. Clear but not sustained effervescence from HCl.		VC_C_7.6		
			0.27- 0.30: Grayish brown (2.5Y 5/2) medium to coarse SAND wiith frequent shell fragments. Clear but not sustained effervescence from HCl.	S-6			
			0.30- 0.66: Grayish brown (2.5Y 5/2) fine to medium SAND with occasional milimetrical to centimetrical clay pockets and occasional shell fragments. No sustained effervescence from HCl (clay with clear but not sustained effervescence from HCl).				
			0.66- 0.70: Grayish brown (2.5Y 5/2) medium to coarse SAND wiith frequent shell fragments. No sustained effervescence from HCl.				
			0.70- 0.90: Dark grayish brown (2.5Y 4/2) fine SAND with occasional shell fragments. No sustained effervescence from HCl.				
1.00			0.90- 1.50: Dark gray (2.5Y 4/1) fine SAND with rare shell fragments. Clear but not sustained effervescence from HCl.	S-5	VC_C_7.5		
			1.50- 1.62: Dark gray (2.5Y 4/1) fine to medium SAND with frequent fine gravel and occasional shell fragments. Clear but not sustained effervescence from HCl.		VC_C_7.4		
2.00		106	1.62- 5.30: Light brownish gray (2.5Y 6/2) fine SAND with rare amorphous organic matter blackish spots. No sustained effervescence from HCl.	S-4			
3.00				S-3	VC_C_7.3		
4.00				S-2	VC_C_7.2		
5.00				S-1	VC_C_7.1		

Bottom at 5.30 m

DETAILED PHOTOS






FIELD VERSION

POINT: VC_C_8
COORDINATES (UTM)
N 5954761.23 m
E 729111.94 m
Water depth 22.40 m

START DATE: 9/5/19
FINISH DATE: 9/5/19
GEOLOGIST: MC/AV
STANDARD: BS EN 5930:2015

EQUIPMENT: Vibrocore
DRILLER: JC
ASSISTANT: MC

REMARKS:

LEGEND

SAND CLAY

DEPTH (m BGL)	C.BARREL/C.SIZE (mm)	MATERIAL DESCRIPTION	SAMPLE TYPE-NUM	Selected SAMPLES for laboratory tests
		0.00- 0.57: Light yellowish brown (2.5Y 6/4) fine to medium SAND with occasional shell framents. No sustained effervescence from HCl.	S-6	VC_C_8.6
		0.57- 0.99: Light yellowish brown (2.5Y 6/4) fine SAND with occasional shell framents. No sustained effervescence from HCl.		
1.00		0.99- 1.17: Dark gray (2.5Y 4/1) fine SAND with frequent amorphous organic matter blackish milimetrical layers and pockets, occasional shell fragments (medium sand to medium gravel sized). No sustained effervescence from HCl.		VC_C_8.5
		1.17- 1.40: Very dark gray (2.5Y 3/1) fine SAND with frequent amorphous organic matter blackish milimetrical layers and pockets and rare shell fragments. Clear but not sustained effervescence from HCl. · From 1.38m to 1.40m: medium SAND.		
		1.40- 1.43: Black (2.5Y 2.5/1) CLAY. No sustained effervescence from HCl.	S-5	
		1.43- 1.80: Dark gray (2.5Y 4/1) fine SAND with occasional medium sand, frequent amorphous organic matter blackish zones, frequent shell fragments. Clear but not sustained effervescence from HCl. · From 1.50m to 1.70m: frequent centimetrical clay pockets. · From 1.60m to 1.80m: medium SAND with rare fine gravel.		
2.00		1.80- 2.00: Grayish brown (2.5Y 5/1) medium SAND with occasional shell fragments. No sustained effervescence from HCl.		
		2.00- 2.10: Grayish brown (2.5Y 5/1) coarse SAND with frequent shell fragments. No sustained effervescence from HCl.		
		2.10- 2.50: Gray (2.5Y 5/1) fine SAND with occasional fine to coarse gravel, rare clay pockets and occasional shell fragments. No sustained effervescence from HCl.	S-4	VC_C_8.4
3.00	106	2.50- 5.50: Light brownish gray (2.5Y 6/2) fine SAND. No sustained effervescence from HCl.	S-3	VC_C_8.3
4.00			S-2	VC_C_8.2
5.00			S-1	VC_C_8.1

Bottom at 5.50 m

Undrained Shear Strength Su (kPa)
⊗ TV ☐ PP
50 100 150 200

REMARKS

DETAILED PHOTOS

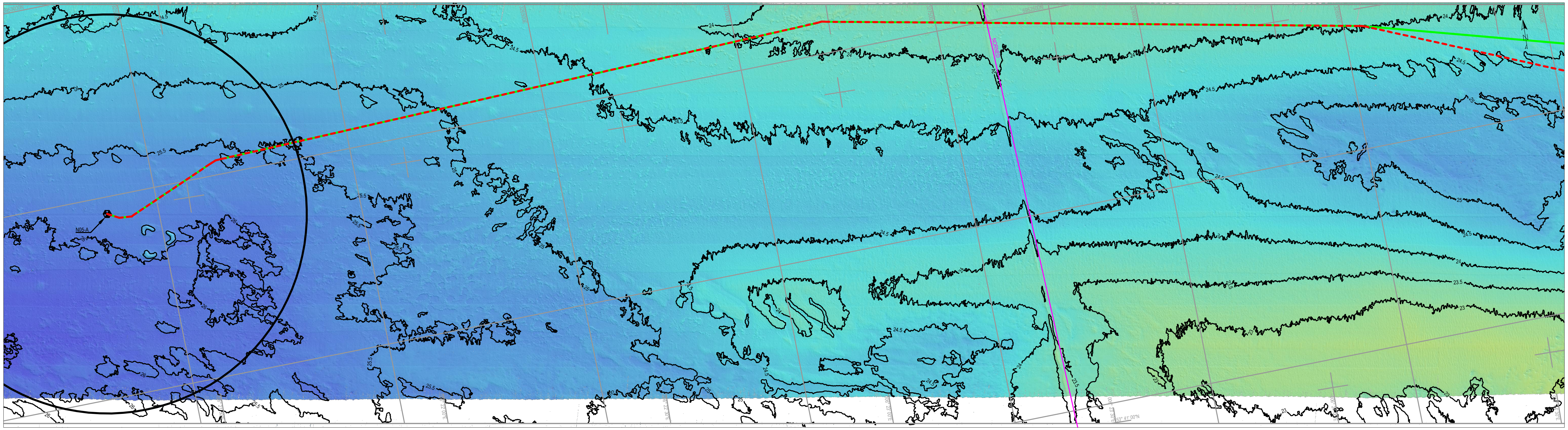


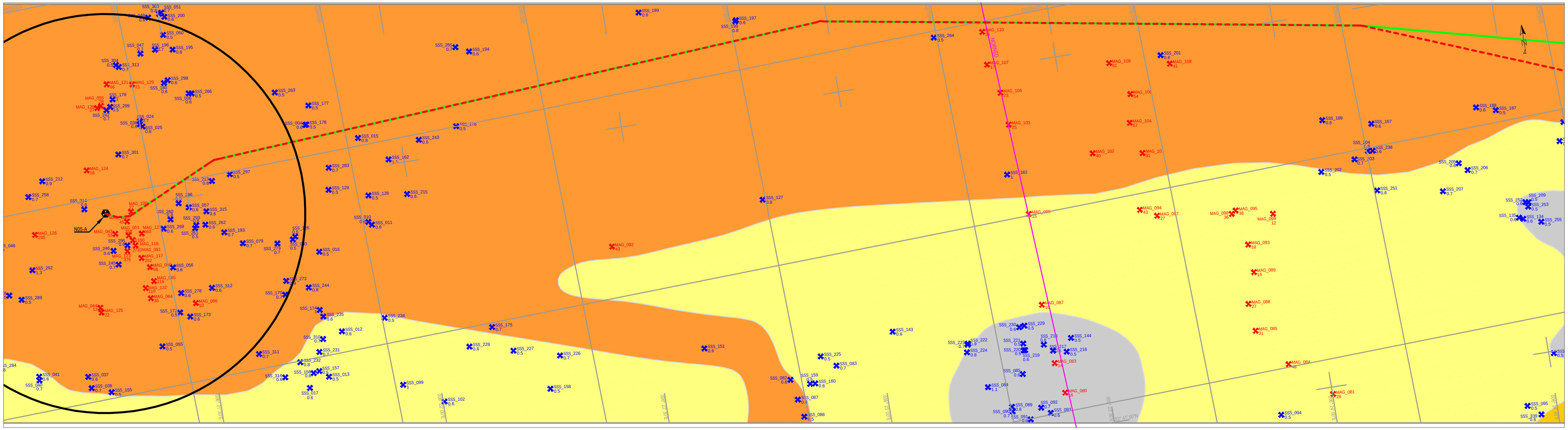



APPENDIX B – CHARTING

Table 9: List of charts

Chart No.	Chart type	Filename
01	Alignment Chart 1 of 3 (ED50)	N05A-7-50-0-72006-01
02	Alignment Chart 2 of 3 (ED50)	N05A-7-50-0-72007-01
03	Alignment Chart 3 of 3 (ED50)	N05A-7-50-0-72008-01
04	Alignment Chart 1 of 3 (WGS84)	N05A-7-50-0-72013-01
05	Alignment Chart 2 of 3 (WGS84)	N05A-7-50-0-72014-01
06	Alignment Chart 3 of 3 (WGS84)	N05A-7-50-0-72015-01





Infrastruktur

- Kabeltrasse OPTION 1b
- geplante Alternativtrasse
- 500m Sicherheitszone
- N05-A Plattform
- Windparkgebiet
- Innerparkkabel Riffgat
- WEA-Standort Riffgat
- NorNed-Kabel

Bathymetrie

-35m -30 -25 -20 -15 -10 -5m

Grid: 0.5m Tiefe (m)

20 Tiefenlinien Intervall 0,5m

Sedimente

- Feinsedimente
- Grobsedimente
- Mischsedimente
- Sand bis kiesiger Sand
- Mischsedimente inkl. Ton

Objekte

- SSS_266 0.8 — SSS Kontakt/Objekt
- MAG_158 0.6 — Magnetometer Kontakt
- DEB_023 1.4 x 0.5 x 0.3 — Geröll / Findling

Quelle: GEOxyz Offshore / Survey Report - N05A-7-10-0-70023-01.2.0

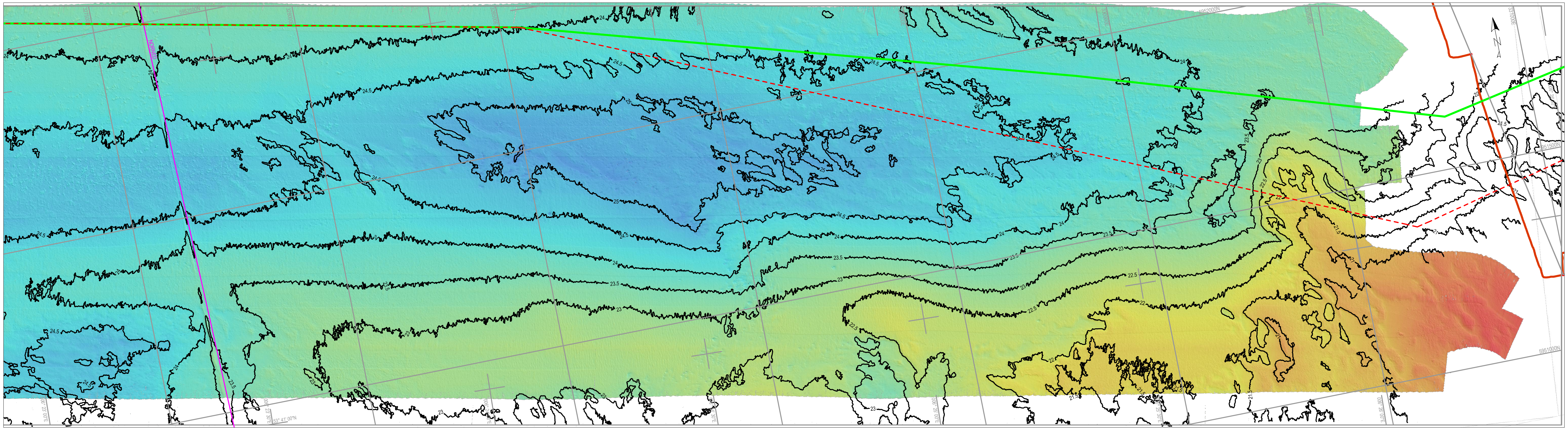
Revision	DD	MM	YYYY	REVISIONSBESCHREIBUNG	Zeichner	Prüfer	Freigabe
C							
B							
A							
01	19	10	2020	Genehmigungsplanung	HJM	DHE	
	Revisions Datum						

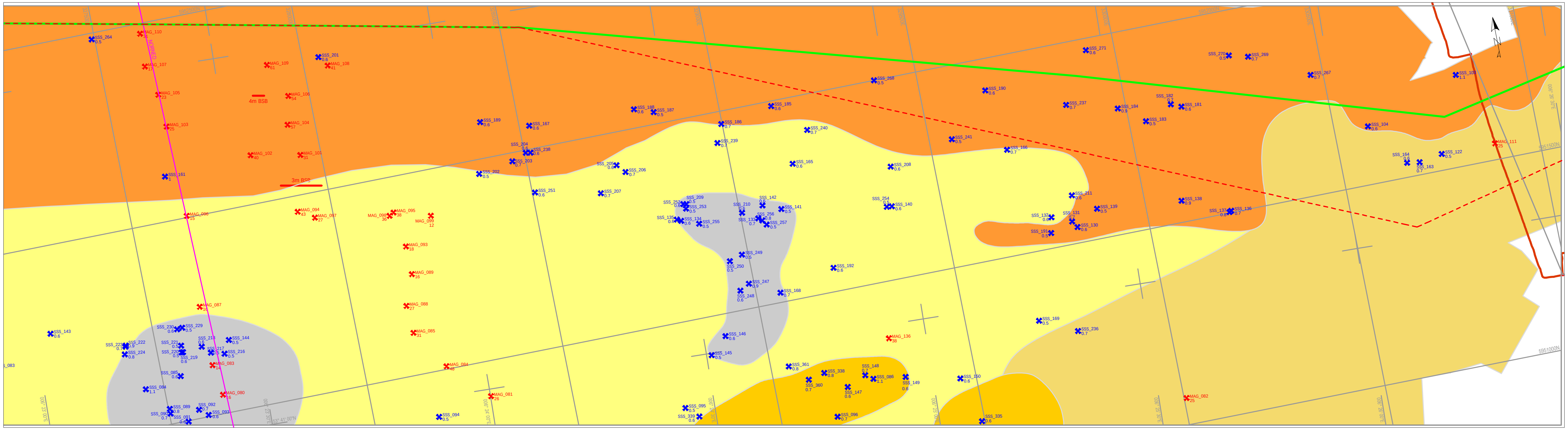
Erstellt: EWE Offshore Service and Solutions GmbH | Maßstab: 1:10.000 | Papiergröße: A3

TITEL: Kabelverbindung N05–A – OWP RIFFGAT
Bathymetrie und Sedimente
Blatt 01

ORANJE-NASSAU ENERGIE — Oranje-Nassau Energie B.V. Amsterdam

ASSETCODE	DISC.CDE	DOC.TYPE CDE	PREFIX	DOCUMENT NUMBER	SHEET NR	REVISION
N05A	5	50	0	52003	01	01





Infrastruktur

- Kabeltrasse OPTION 1b
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C							
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01	19	10	2020	Genehmigungsplanung	HJM	DHE	
	Revisions Datum						

Erstellt	EWE Offshore Service and Solutions GmbH	Maßstab	1:10.000	Papiergröße	A3	

TITEL: Kabelverbindung N05–A – OWP RIFFGAT
Bathymetrie und Sedimente
Blatt 02

ORANJE-NASSAU ENERGIE

Oranje-Nassau Energie B.V.
Amsterdam

ASSETCODE	DISC.CDE	DOC.TYPE CDE	PREFIX	DOCUMENT NUMBER	SHEET NR	REVISION
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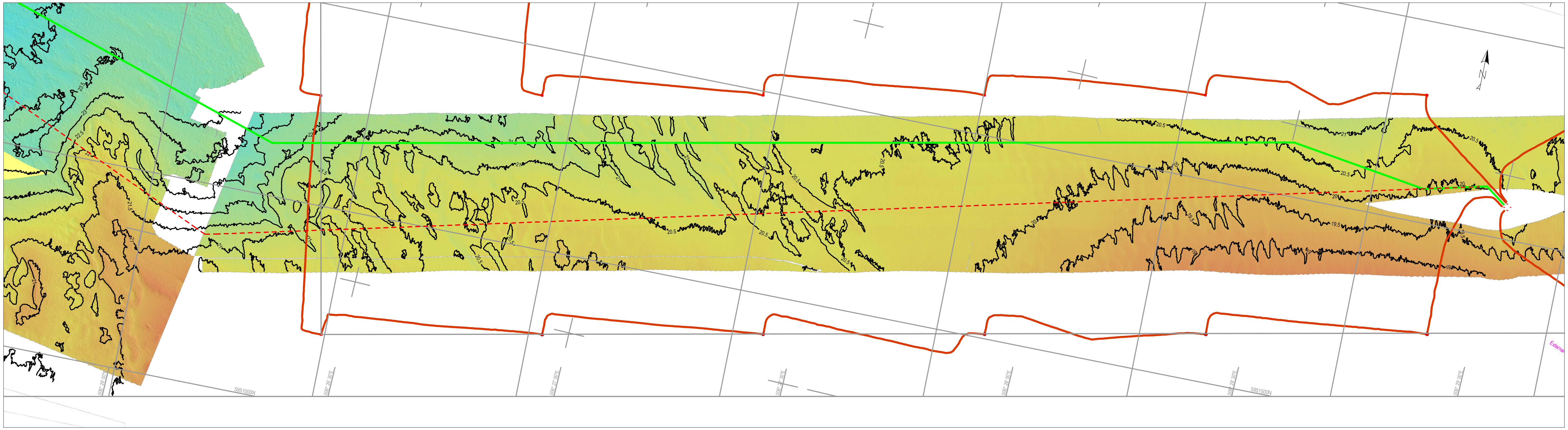

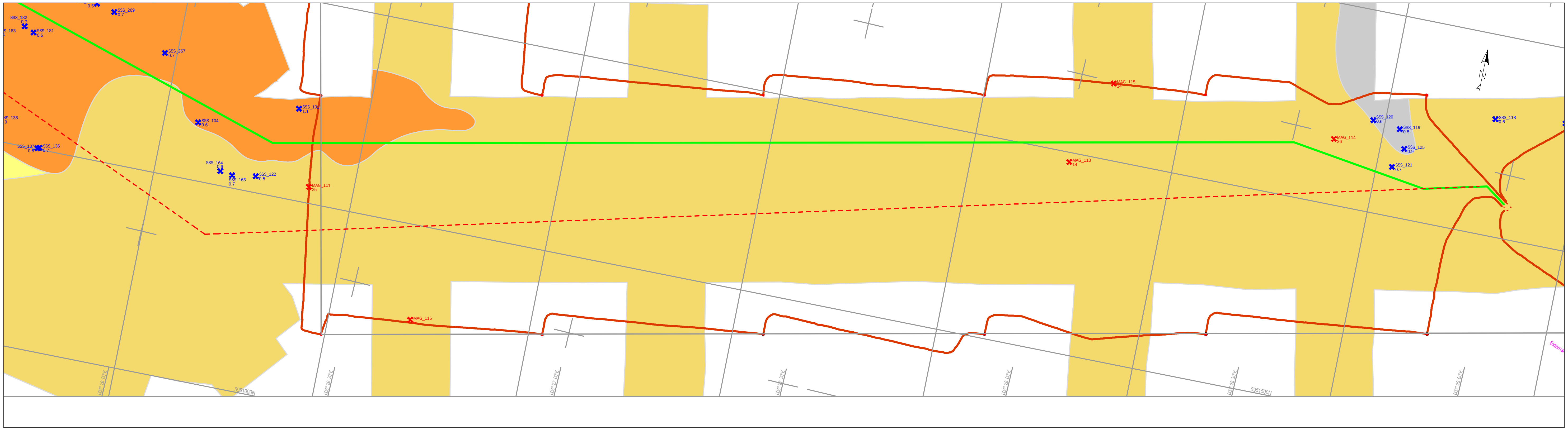

Infrastruktur

- Kabeltrasse OPTION 1b
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-35m -30 -25 -20 -15 -10 -5m

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- Mischsedimente inkl. Ton

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Revision	DD	MM	YYYY	REVISIONSBESCHREIBUNG	Zeichner	Prüfer	Freigabe
C							
B							
A							
01	19	10	2020	Genehmigungsplanung	HJM	DHE	
	Revisions Datum						

Erstellt	EWE Offshore Service and Solutions GmbH	Maßstab	1:10.000	Papiergröße	A3

TITEL

Kabelverbindung N05–A – OWP RIFFGAT
Bathymetrie und Sedimente
Blatt 03

ORANJE-NASSAU ENERGIE

Oranje-Nassau Energie B.V.
Amsterdam

ASSETCODE	DISC.CDE	DOC.TYPE CDE	PREFIX	DOCUMENT NUMBER	SHEET NR	REVISION
N05A	5	50	0	52003	03	01

TKF CONNECTIVITY SOLUTIONS

Technical Report

N05-A

Electromagnetic field of submarine cable

Document details

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Document status history & authorization

State	Updater	Verifier	Date of change	Revision	Revision comment
Under editing			11 Jun 20	S3	Work on document with simulation results
Waiting for internal approval			16 Jun 20	P4	
Internally approved			02 Jul 20	C3	approved
For review at customer			02 Jul 20	C4	send out for review to customer
Approved			13 May 20	02	Internally approved for issue to client
-	-	-	-	-	-
-	-	-	-	-	-

Table of Contents

Michel Mens

Abbreviations

The abbreviations as used in the text are to be interpreted as defined below:

CSA	Cross Sectional Area
CUSTOMER	ONE-Dyas B.V.
DOB	Depth Of Burial
DOC	Depth Of Cover
FEM	Final Element Modelling
PROJECT	N05-A
SUPPLIER	Twentsche Kabelfabriek
TKF	Twentsche Kabelfabriek
FEM	Finite element method

SUPPLIER applies the International System of Units (SI) and therefore units like for instance; MW, kA, s etcetera's and their accompanying explanation are not mentioned in this list.

1 Introduction

The purpose of this document is to report the calculated value of the electromagnetic field of two submarine cables selected potentially for the PROJECT. In earlier stage a range of calculations was executed and reported on part of SUPPLIER's submarine cable portfolio. The input for these calculations are summarized in chapter 3 and the results in chapter 4. CUSTOMER chose two scenario's i.e. CSA's for a next step calculations. This concerns the electromagnetic field level in Gauss or µT that the cable is going to emit at the level of the seabed surface. Chapter 5 elaborates on the method chosen for determining the lector-magnetic field and Chapter 6 mentions the results and if possible conclusions.

2 Input

The input parameters are provided by CUSTOMER with the exception however of the last group of parameters in this chapter. These seabed electrical parameters however are reasonable assumptions.

Electrical parameters:

Operational voltage level	19/33 (36) kV
Power:	23595 kVA
Cosinus phi:	0.88
Total cable length:	9000 meter
Voltage drop:	= < 10%

Environmental parameters:

Thermal resistance seabed soil	0.39 K*m/W
DoC	1.5 m
Seabed soil temperature	15 degrees Celsius

Seabed electrical parameters:

Seabed electrical conductivity	1.0 S/m
Seabed relative electrical permeability	1.0
Seabed relative electrical permittivity	25
Seawater electrical conductivity	5.0 S/m
Seawater relative electrical permeability	1.0
Seawater relative electrical permittivity	81

3 Calculations for cable selection

Based on above mentioned input parameters the actual current in the cable will be 413 A.

Table 1. summary of cable types in the PROJECT.

Cable configuration	CSA (mm^2)	Iscc (kA/1s)	Uo voltage drop (V)	Uo voltage drop (%)	seabed temp. rise[1]	Ampacity (A)	Comment
149186	400	37.8	547	2.9%	0.9	665	option 4
149288	300	27.9	647	3.4%	1.1	585	option 3
149166	240	22.6	757	4.0%	1.4	518	option 2
149368	185	17.3	933	4.9%	1.8	447	option 1
149364	150	13.8	1121	5.9%	2.4	394	Too low on ampacity

[1]Seabed temperature rise @ -200mm below seabed surface and 413 A

CLIENT chose option 1 and 3 to continue with for determining the electro-magnetic field.

4 Calculation method for electromagnetic field

Finite element method (FEM) is applied to calculate the electro-magnetic field in and around submarine cable buried in seabed. COMSOL is chosen to be the simulation software. One 2D FEM model will be generated in COMSOL software for each cable (option 1 and option 3 scenario's). Electrical conductivity, electrical permeability and electrical permittivity of the seabed soil is taken by reasonable assumptions. Since there is no existing standards to guide the FEM simulation, published scientific papers are used as the guidance for the simulation work [1, 2, 3].

4.1 Cable models

2D Cable models based on TKF cable dimensions are built in COMSOL. The cable cross section area is chosen in such a way that the lay-direction of power cores and fibre optical (FO) cables will represent the worst case scenario, in which the emitted magnetic flux density at seabed surface direct above the cable axis has the highest value.

In actual TKF cables for both types, conductors are stranded Al. wires, with swellable yarns in between the wires. For the sake of simulation simplicity, in the model cable conductor is built as massive Al. conductor with diameter the same as cable datasheet value. Electrical conductivity of the conductor material, instead, is adjusted so that the total conductor electrical resistivity matches with the values defined in IEC60228 [4]. This simplification will not influence the simulation results.

As an example, 3×300mm2 cable model is given in figure 1 below. 3×185mm2 cable have the same structure, but only different dimension compared to 3×300mm2 cable.

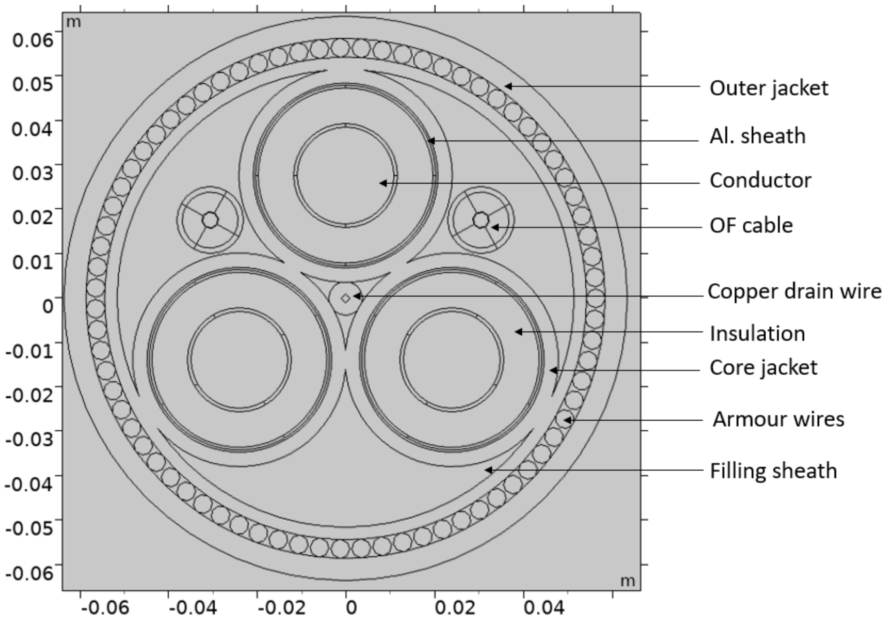


Figure 1. 2D cable model for 3×300mm2 built in COMSOL.

Cable is buried in seabed with depth of coverage 1.5 meter, as can be seen in an example of complete model in the COMSOL in figure 2.

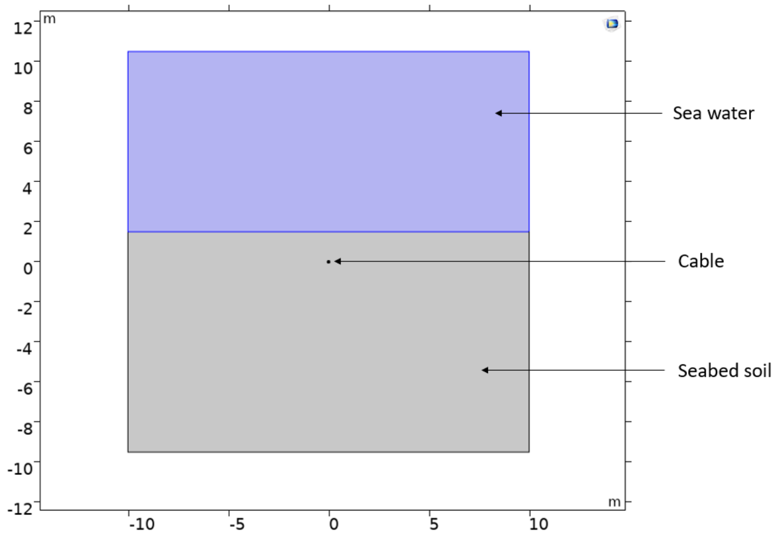


Figure 2. Complete model for cable buried in seabed in COMSOL. Rectangular on top marked with blue colour represents seawater. Rectangular on bottom represents seabed.

4.2 EM parameters

Electro-magnetic parameters of the cable and its surrounding environment will have influence on the simulation results. In table 2 below electro-magnetic parameters for the components are summarized.

Table 2. Electrical magnetic properties of the cable material and its surrounding environment. R_c −electrical resistance of conductor defined by IEC60228, in unit of Ω/m; A_c −cross section area of conductor material, in unit of m^2.

	Relative electrical permittivity	Relative electrical permeability	Electrical conductivity (S/m)
Conductor (Al.)	1.0	1.0	$1/(R_c A_c)$
XLPE insulation	2.5	1.0	1×10^{-18}
Insulating PE material	2.5	1.0	1×10^{-14}
Semi-conductive conductor/insulation screen	2.3	1.0	1
Semi-conductive PE over core jacket and FO cable jacket	2.3	1.0	4
Earth screen (welded Al. tube)	1.0	1.0	3.521×10^{7}
Amour wire	1.0	600	7.246×10^{6}
Seabed	81	1.0	1.0
Seawater	25	1.0	5.0

5 Simulation results

Magnetic and Electric Fields model in COMOSL was used to simulate the electrical magnetic field within and around the cables. PROJECT current defined in table 1 is applied in both cables during the simulation, i.e., 413A for both 3×185mm2 cable and 3×300mm2 cable. Phase to ground voltage of 19kV was applied between conductor and earth screen. Surface plot for electrical field and contour plot of the magnetic flux density are plotted for each cable type, under stationary solution.

For the sake of better illustration, the magnetic flux density results are presented in three plots for each cable type.

5.1.1 3×185mm2 cable

- **Electrical field**

Electrical field only exists within the cable insulation parts, and is independent on the environmental situation and the applied load. With applied phase to ground voltage of 19kV, electrical field distribution within 3×185mm2 cable is simulated, and result is illustrated in figure 3. Maximum electrical field appears on the conductor screen: 3.3kV/mm and minimum electrical field appears on the outer side of insulation: 1.8kV/mm.

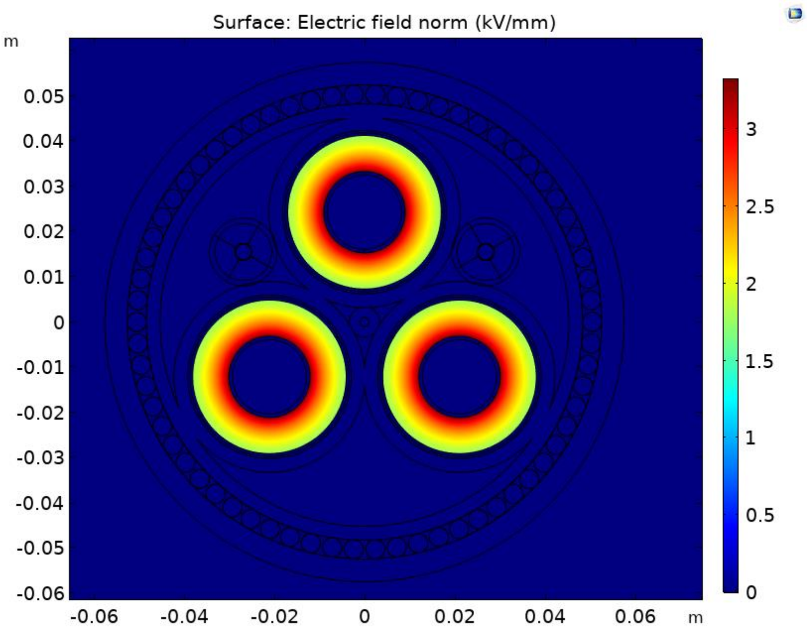
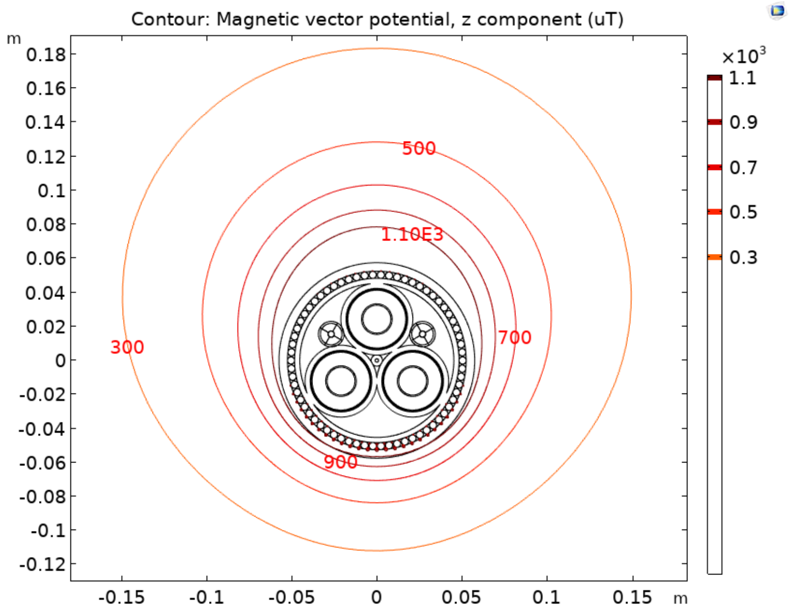
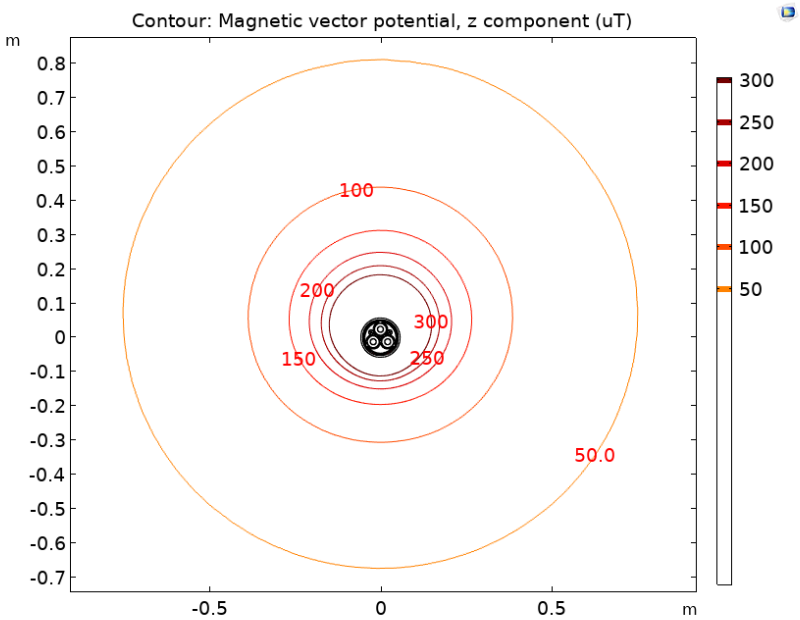


Figure 3. electrical field distribution in 3×185mm2 cable under phase to ground voltage of 19kV.

- **Magnetic field**

Three plots in figure 4 are used to present the magnetic flux density within and around the 3×185mm2 cable, under peak PROJECT load. From the results we can see that the magnetic flux density is mostly constrained within the cable. At location 0.1mm adjacent to the cable outer surface, magnetic flux density is 1.9mT. At distance of 50cm away from the cable outer surface, highest magnetic flux density decreases to 76μT. At the seabed surface direct above the cable axis, magnetic flux density emitted by the cable is 26μT. At distance of 2meter away from the cable outer surface, highest magnetic flux density decreases to19μT.


Contour: Magnetic vector potential, z component (uT)
m
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
m
×10^3
1.1
0.9
0.7
0.5
0.3
500
1.10E3
300
700
900


Contour: Magnetic vector potential, z component (uT)
m
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.5
0
0.5
m
300
250
200
150
100
50
100
200
300
150
250
50.0

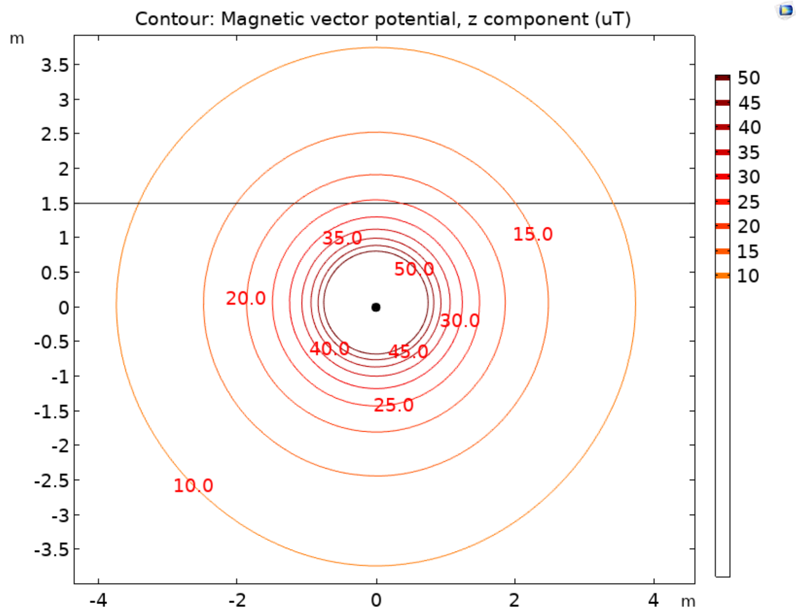


Figure 4. Magnetic flux density within and around 3×185mm2 cable, under peak PROJECT load: 413A.

5.1.2 3×300mm2 cable

- **Electrical field**

Electrical field only exists within the cable insulation parts, and is independent on the environmental situation and the applied load. With applied phase to ground voltage of 19kV, electrical field distribution within 3×300mm2 cable is simulated, and result is illustrated in figure 5. Maximum electrical field appears on the conductor screen: 3.1kV/mm and minimum electrical field appears on the outer side of insulation: 1.9kV/mm.

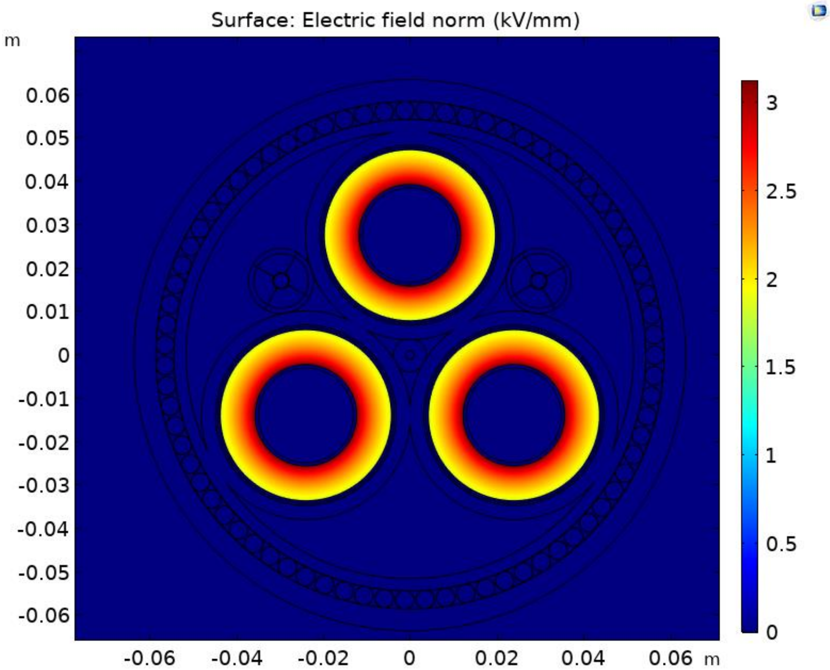
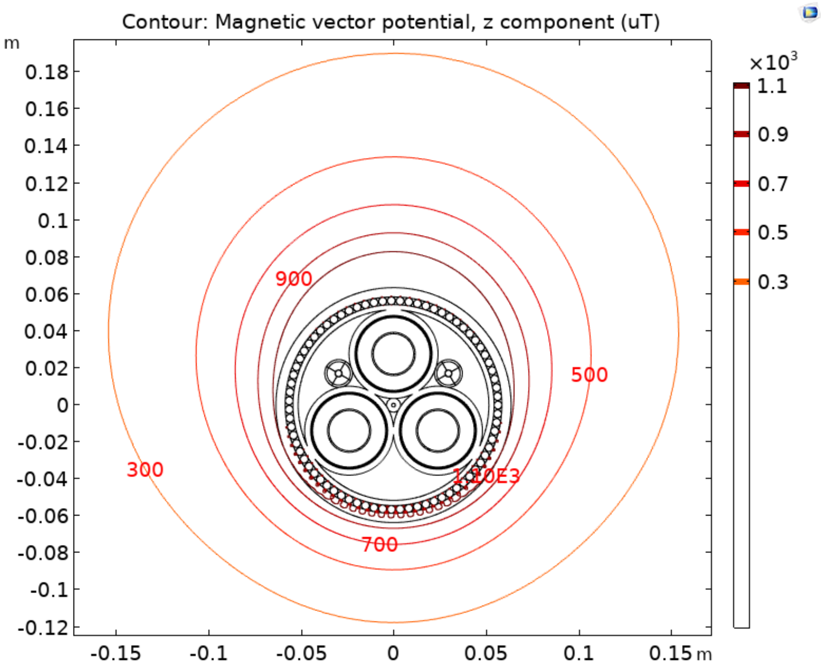
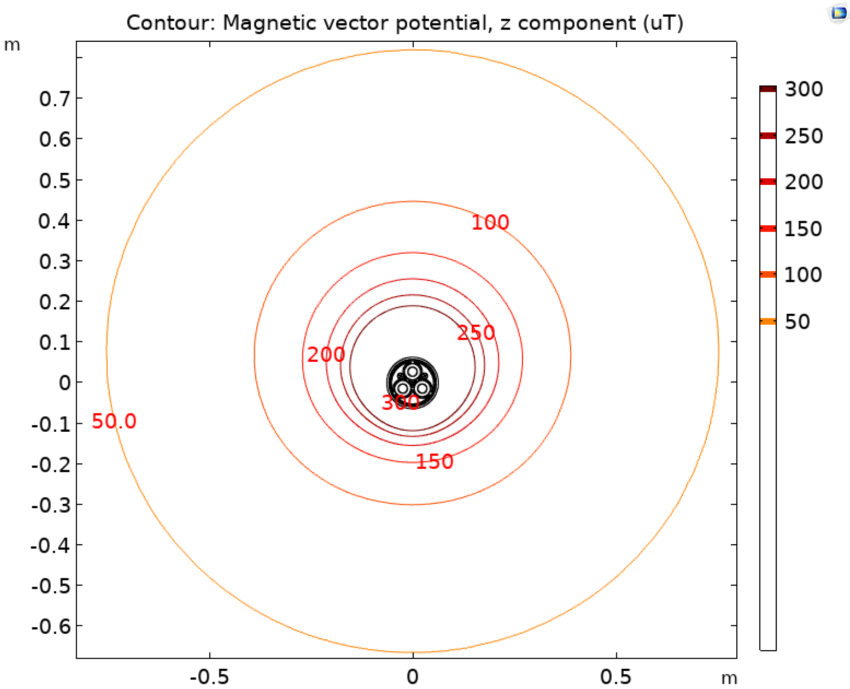


Figure 5. electrical field distribution in 3×300mm2 cable under phase to ground voltage of 19kV.

- **Magnetic field**

Three plots in figure 6 are used to present the magnetic flux density within and around the 3×300mm2 cable, under peak PROJECT load. From the results we can see that the magnetic flux density is mostly constrained within the cable.
At location 0.1mm adjacent to the cable outer surface, magnetic flux density is 1.8mT. At distance of 50cm away from the cable outer surface, highest magnetic flux density decreases to 77μT. At the seabed surface direct above the cable axis, magnetic flux density emitted by the cable is 26 μT. At distance of 2meter away from the cable outer surface, highest magnetic flux density decreases to19μT.





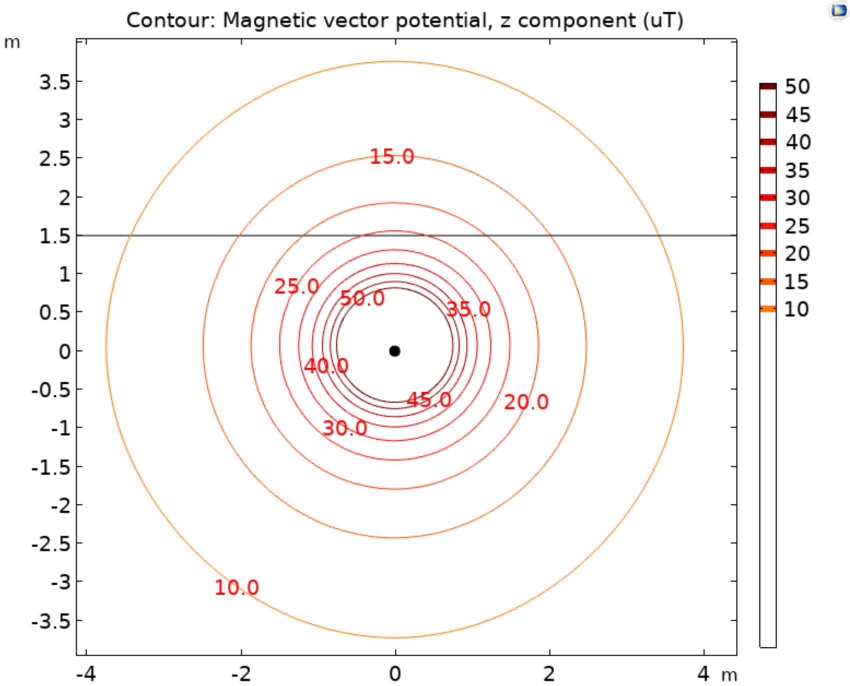


Figure 6. Stationary Magnetic flux density within and around 3×300mm2 cable, under PROJECT load: 413A.

6 Conclusion

Electrical and magnetic field emitted by both PROJECT cables 3×185mm2 and 3×300mm2 are simulated using FEM model. Electrical field are constrained within the cable insulation, due to the earth screen on each core. Magnetic flux density within and around cable 3×185mm2 and 3×300mm2 cables under PROJECT current are simulated using 2D FEM model. For both cables, magnetic flux density on the cable outer surface is less than 2mT, while within less than 1meter away from the cable surface, the magnetic flux density decreases to tens of micro-tesla, which is in the same range as background magnetic flux density in the earth. At the seabed surface, magnetic flux density emitted by both 3×185mm2 and 3×300mm2 cables is 26μT.

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Report

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Table of content

1 Scope of Study

A new station owned by ONE DYAS is to be connected to the 33-kV-grid of the 155-kV-/33-kV-grid of offshore wind farm (OWF) Riffgat [1]. A submarine cable with a length of approx. 9 km is planned to be laid. The power requirement of the station is approx. 20 MW (24 MVA). The required minimum cross section of the submarine cable is calculated by means of power flow calculations [1]. A minimum cross section of 300 mm² is recommended to carry the current. The maximum load current of one phase is about 460 A.

Additionally, from nature conservation point of view, the warming of the seabed above the cable must be limited. A maximum warming of 2 Kelvin in 300 mm below the seabed (above the cable) is required, which is called the 2-K-criterion [2]. In this report the heating losses of the cable project and the calculation of the 2-K-criterion is presented. The 2-K-criterion is calculated for three different cable cross sections (300, 400 and 500 mm²).

2 Basis of Calculations

2.1 Properties of the Seabed

The specific thermal resistance ρ_T of water saturated seabed is 0.33 to 0.50 K·m/W [3]. The "Geo-Engineering.org GmbH" has measured the thermal conductivity of the seabed of the offshore wind farm Riffgat in 2011 [3]. At a depth between 1.45 and 1.55 m a thermal resistance ρ_T between 0.39 and 0.37 K·m/W is measured. As a conservative approach the 2-K-criterion is calculated at a value of ρ_T = 0.39 K·m/W. The temperature of the seabed is assumed to be 10 °C [2]. The calculation is performed for a cable laid 1.5 m under the seabed.

2.2 Cable System

For the calculation a 30 kV submarine power cable is used (2XS(FL)2YRAA 18/30(36) kV) [4]. The thermal resistances and the cable loses are calculated with the help of the constructional data (Figure 1) and the electrical data (Figure 2) of the datasheet [4].

1	2	3	4	5	6		7	8	9	10	11
Nominal cross sectional area of conductor	Conductor copper round stranded diameter over conductor	Insulation XLPE wall thickness	Screen copper wires and counter helix cross sectional area	Metallic tape aluminium wall thickness	Core sheath PE black wall thickness	diameter	Bedding wall thickness	Armour steel wires round galvanized diameter	Serving bitumen fib. material and lime wash wall thickness	Outer diameter of cable	Cable weight
(mm²)	(mm)	(mm)	(mm²)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(t/km)
300	20.6	8.0	25	0.2	2.5	47	2	4.2	4.0	121	24.1
400	23.8	8.0	35	0.2	2.5	50	2	4.5	4.0	129	28.1
500	26.6	8.0	35	0.2	2.6	53	2.5	5.0	4.0	137	33.4

Figure 1 - Constructional Data [4]

1		2	3	4	5	6	7	8	9	
Nominal cross sectional area		Conductor resistance DC 20°C	Conductor resistance AC 90°C	Screen resistance 20°C	Capacitance	Inductance	Current rating	Losses	1s short circuit current after full load at 90°C conductor temperature	
conductor (mm²)	screen (mm²)	(Ω/km)	(Ω/km)	(Ω/km)	(μF/km)	(mH/km)	(A)	(W/m)	conductor (kA)	screen (kA)
300	25	0.0601	0.079	0.73	0.25	0.35	564	83	43.3	5.1
400	35	0.0470	0.063	0.53	0.28	0.34	627	86	57.8	7.1
500	35	0.0366	0.050	0.53	0.32	0.32	699	88	72.2	7.1

Figure 2 - Electrical Data [4]

2.3 Cable losses of a 3-phase submarine cable

To calculate the cable losses of a 3-phase submarine cable different losses and thermal resistances have to be considered. The main losses are the $I^2 \cdot R$-losses (W_c) of the conductor. With higher temperature of the cable, the resistance of the conductor, the sheath and the armour increases. Therefore, the losses in the whole cable increases. Additionally the Skin effect and the proximity effect in the sheath (W_s) and the armour (W_a) are considered. According to IEC 60287-1-1, dielectric losses (W_d) are not considered in voltage levels under 127 kV [5]. In Figure 3 the thermal network of the losses and the thermal resistances of the cables system and the surroundings are given.

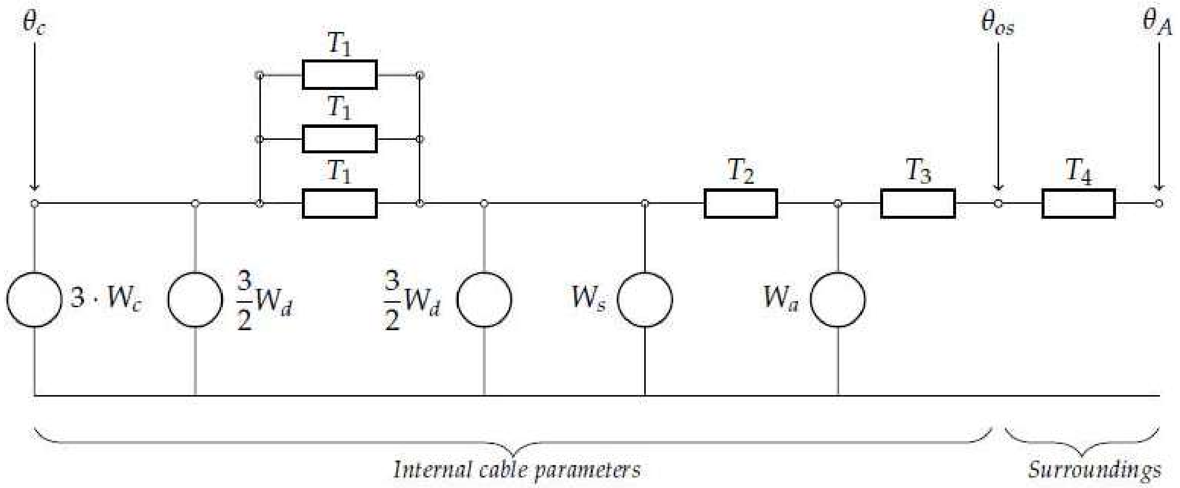

Figure 3 - Thermal resistances (T), heat sources (W) and tempeatures (θ) in a three-core XLPE submarine cable [6]

2.4 Calculation of the 2-K-criterion

Heating is determined using the steady-state method according to IEC 60287-2-1 [7]. This method is based on the stationary state of the heat flow. The current constantly maintains the same maximum value and the sea floor is already warmed up. This is a conservative assumption, as the heating behaviour in the seabed is transient and can absorb even more heat. The 2-K-criterion is calculated with the help of the mirroring method according to IEC 6028-2-1 section 2.2.3.1 [7]. The dimensions for this method are given in Figure 4.

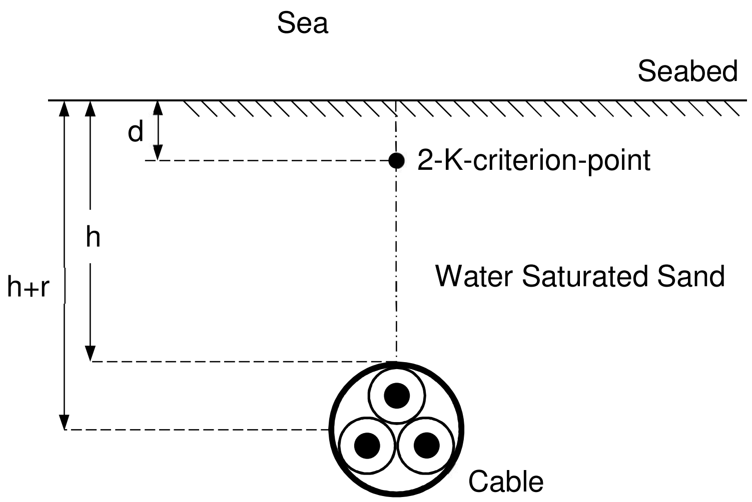

Figure 4 - Schematic illustration of the laying of the cable and the 2-K-criterion-point

The temperature rise $\Delta\theta_{2KP}$ at the 2-K-criterion-point is calculated as follows:

$$\Delta\theta_{2KP} = \frac{1}{2\pi} W_{tot} \cdot \rho_T \cdot \ln\left(\frac{h+r+d}{h+r-d}\right)$$

W_{tot}: total losses

ρ_T: specific thermal resistance of the seabed

h: installation depth of the cable (1500 mm)

d: 2-K-criterion-point (300 mm)

r: radius of the conductor (60.5 – 68.5 mm)

3 Results

In Table 3-1 the different losses for a maximum r.m.s. current of I = 460 A of three different cable cross sections are given. As a result, the steady state values of the total losses W_{tot} and the temperature of the conductor T_c is given.

Table 3-1 - Losses of the calculated cables

	300 mm²	400 mm²	500 mm²
Current in one conductor I (r.m.s)	460 A	460 A	460 A
Cable conductor losses W_c	42.90 W/m	33.60 W/m	26.71 W/m
Skin und proximity losses $W_{s,A}$	15.22 W/m	16.40 W/m	15.85 W/m
Dielectric losses W_d (not considered)	0.38 W/m	0.38 W/m	0.38 W/m
Total losses W_{tot}	58.13 W/m	50.00 W/m	42.56 W/m
Temperature of the conductor T_c	42.27 °C	35.56 °C	30.23 °C

Table 3-2 shows the temperature at the 2-K-criterion-point for the three cables examined. All three cross sections are below the maximum values of 2 K.

Table 3-2 - Losses of the calculated cables

	300 mm²	400 mm²	500 mm²
Current in one conductor I (r.m.s)	460 A	460 A	460 A
Total losses (W_{tot})	58.13 W/m	50.00 W/m	42.56 W/m
$\Delta\theta_{2KP}$	1.40 K	1.21 K	1.02 K

4 Conclusion

The 2-K-criterion in 300 mm below the seabed is fulfilled with 1.40 K (300 mm²), 1.21 K (400 mm²) and 1.02 K (500 mm²) for all cable cross sections. The calculation depends strongly on the boundary conditions such as the installation depth of the cable, the specific thermal resistance of the seabed and the maximum load current. The results are only valid for the given parameters. The calculation is performed with a conservative steady state method.

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