N05-A Pipeline design

Risk assessment & dropped object analysis

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Client

ONE-Dyas B.V.

Project

N05-A Pipeline Design

Document

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Revision History

Revision	Description
01	For Client Comments
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Revision Status

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01	For Client Comments	02-01-2020	JvdB	PF	PF	
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04	Updated for pipeline re-route	15-12-2021	PF	DK	DK	
05	Client comments incorporated	22-12-2022	PF	DK	DK	

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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 @KP141.4. Approximate length of the pipeline is 14.6 km.

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

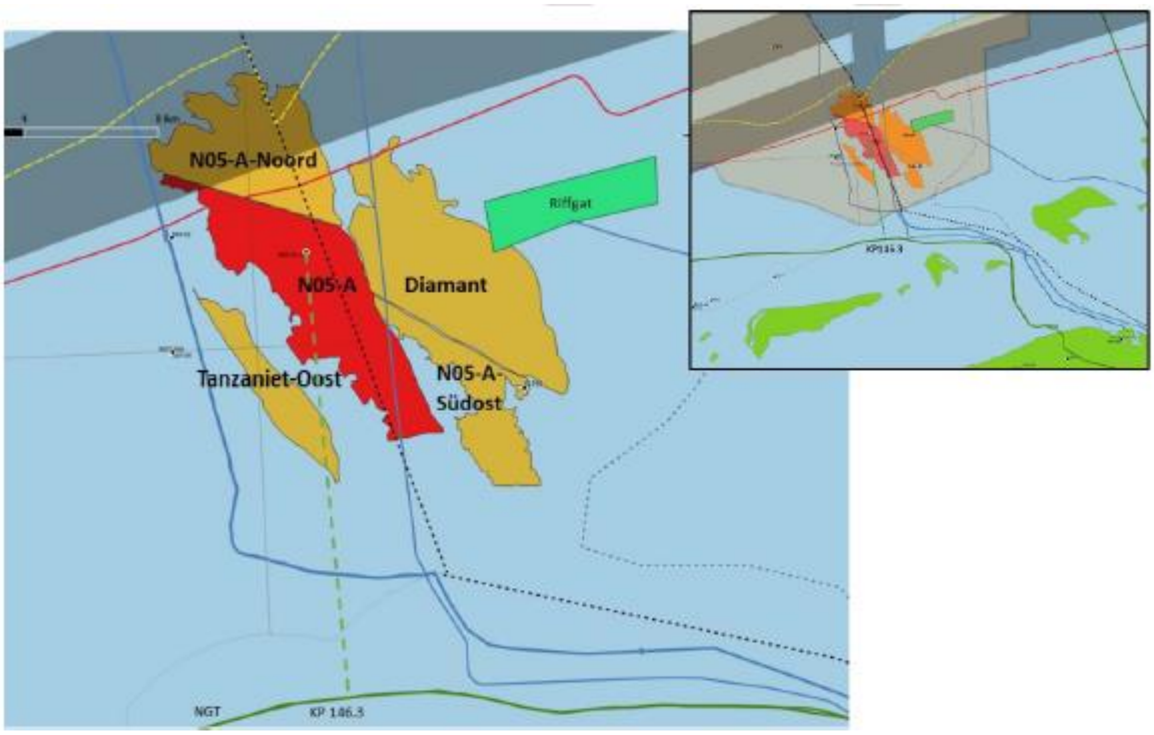


Figure 1, N05A Field layout

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-7-51-0-72510-02-06 - 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 - 2.0	45	0.7	0.97	0.6	0.97	0.5	0.90
2.0 – 7.5	15	0.0	0.74	0.0	0.54	0.0	0.52
7.5 - 12.2	45	0.7	0.97	0.6	0.97	0.5	0.90
12.2 – 14.6	27	0.3	0.89	0.0	0.97	0.0	0.93

*Note: 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, requires 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	5 953 858	721 896
NGT side tap location KP141.4	5 940 197	717 698
N05A Platform target box	5 953 809	721.939
NGT target box	5 940 230	717 669
Water depth at N05A Platform	25.3 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

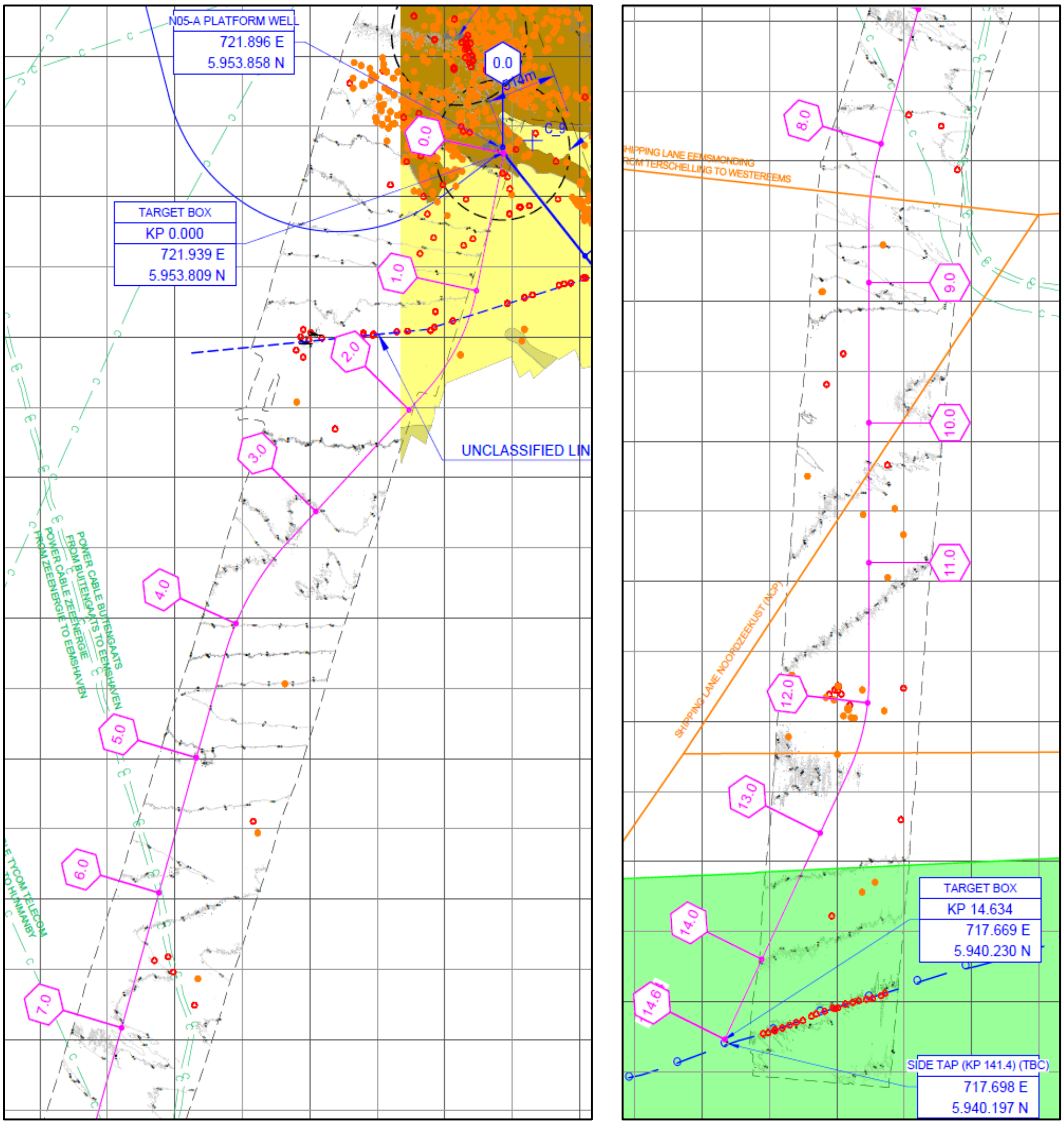


Figure 2, Pipeline route overview

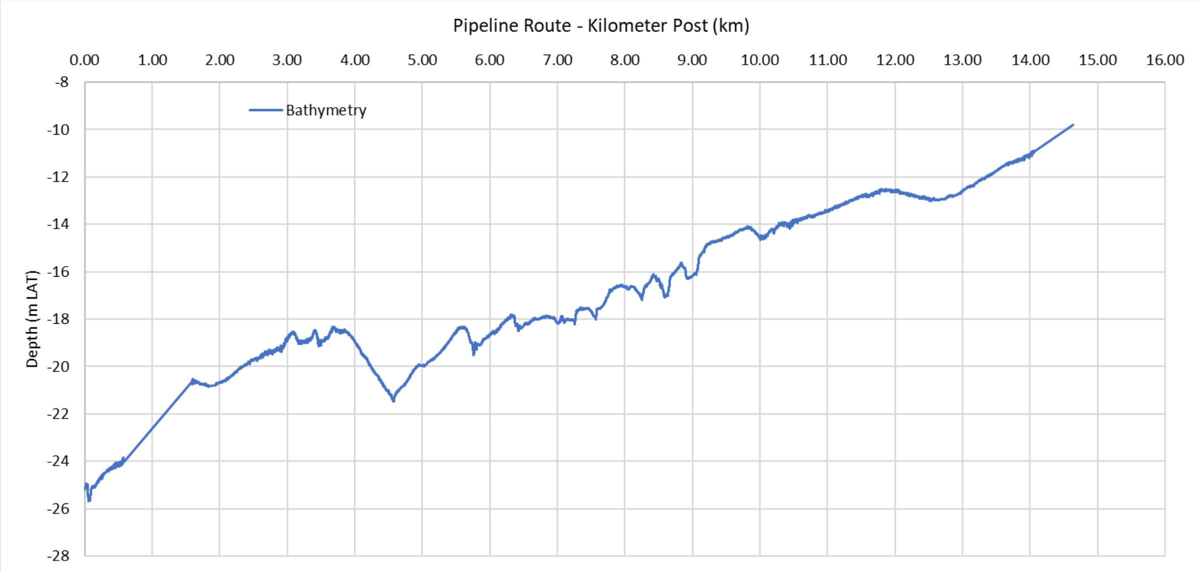


Figure 3, Bathymetric profile along the proposed pipeline route from platform N05A to NGT hot tap, ref [18].

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/m³]	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.

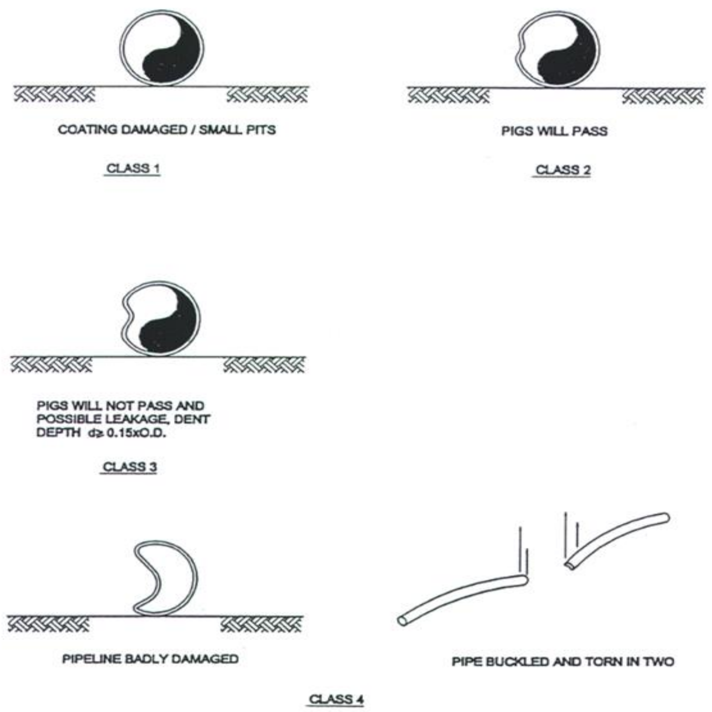


Figure 4, Damage classification

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.

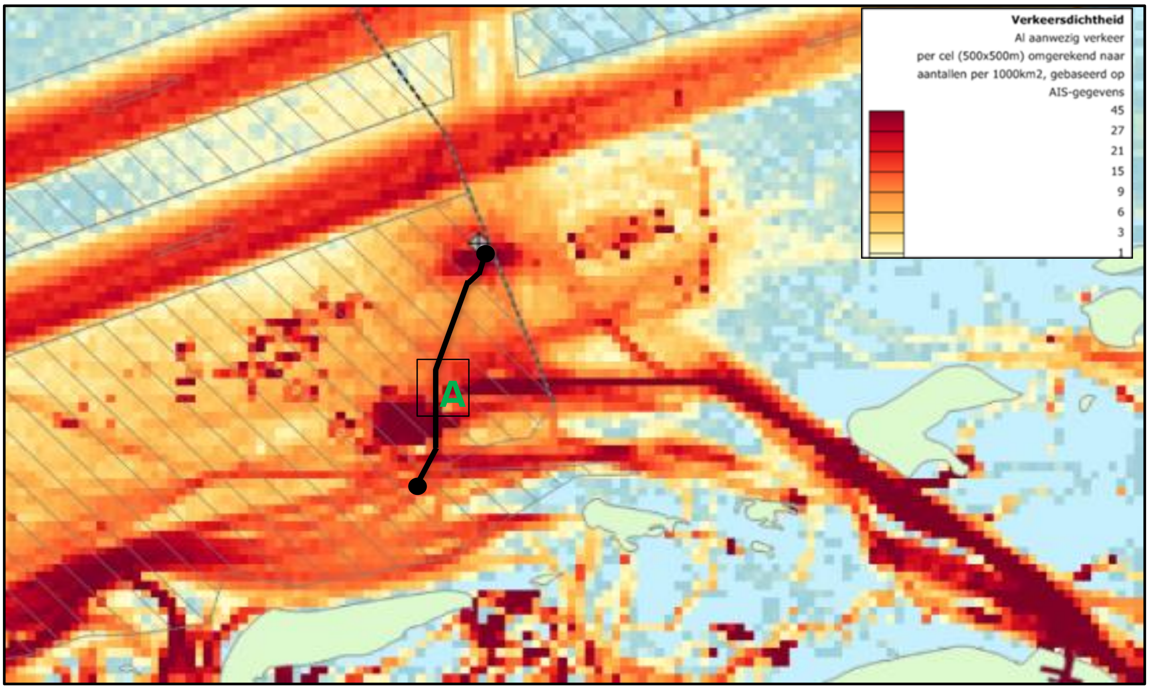


Figure 5, Vessel density maps, based on AIS over 2017 ref [15]], with platform and pipeline. All vessel sizes are shown.

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 $1/\pi$.

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 $1/\pi$ 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

$$N_c = \frac{N_q - 1}{\tan \phi}$$

$$S_c = 1 + 0.2\frac{B}{L}$$

$$D_c = 1 + 0.4\,\text{atan}\frac{y}{B}$$

$$N_q = e^{\pi \tan \phi} \tan^2\left(45 + \frac{\phi}{2}\right)\text{F}$$

$$S_q = 1 + \sin \phi \frac{B}{L}$$

$$D_q = 1 + 2\tan\phi \ (1 - \sin\phi)^2\,\text{atan}\frac{y}{B}$$

$$N_\gamma = 2\left(N_q - 1\right)\tan\phi$$

$$S_\gamma = 1 - 0.4\frac{B}{L}$$

$$D_\gamma = 1$$

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.

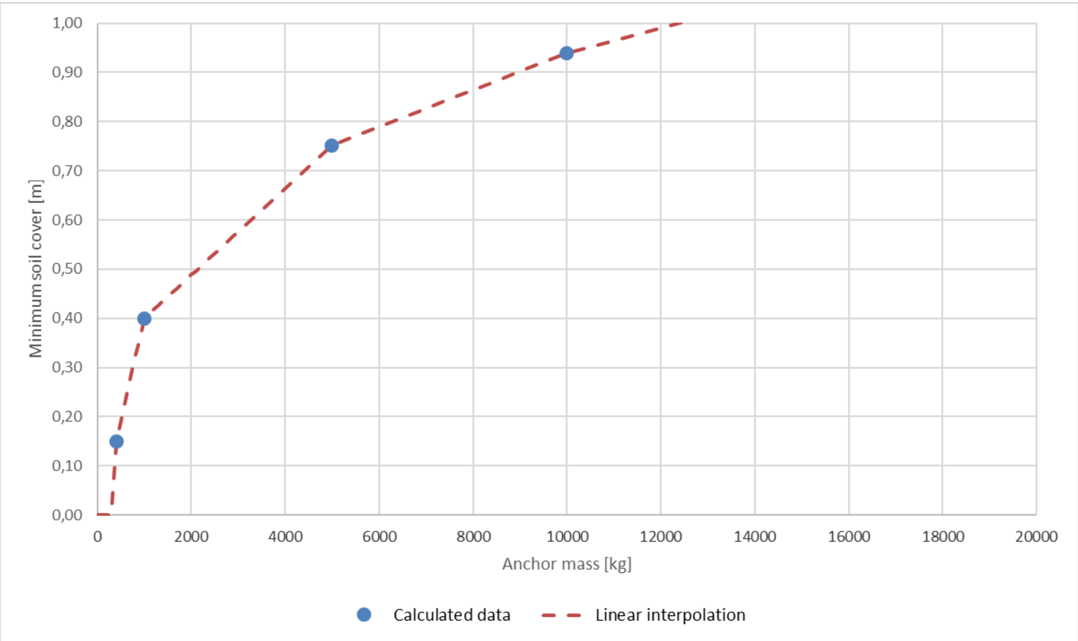


Figure 6 Required minimum soil cover as function of anchor mass (valid > 1200kg)

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 /1000km²
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.

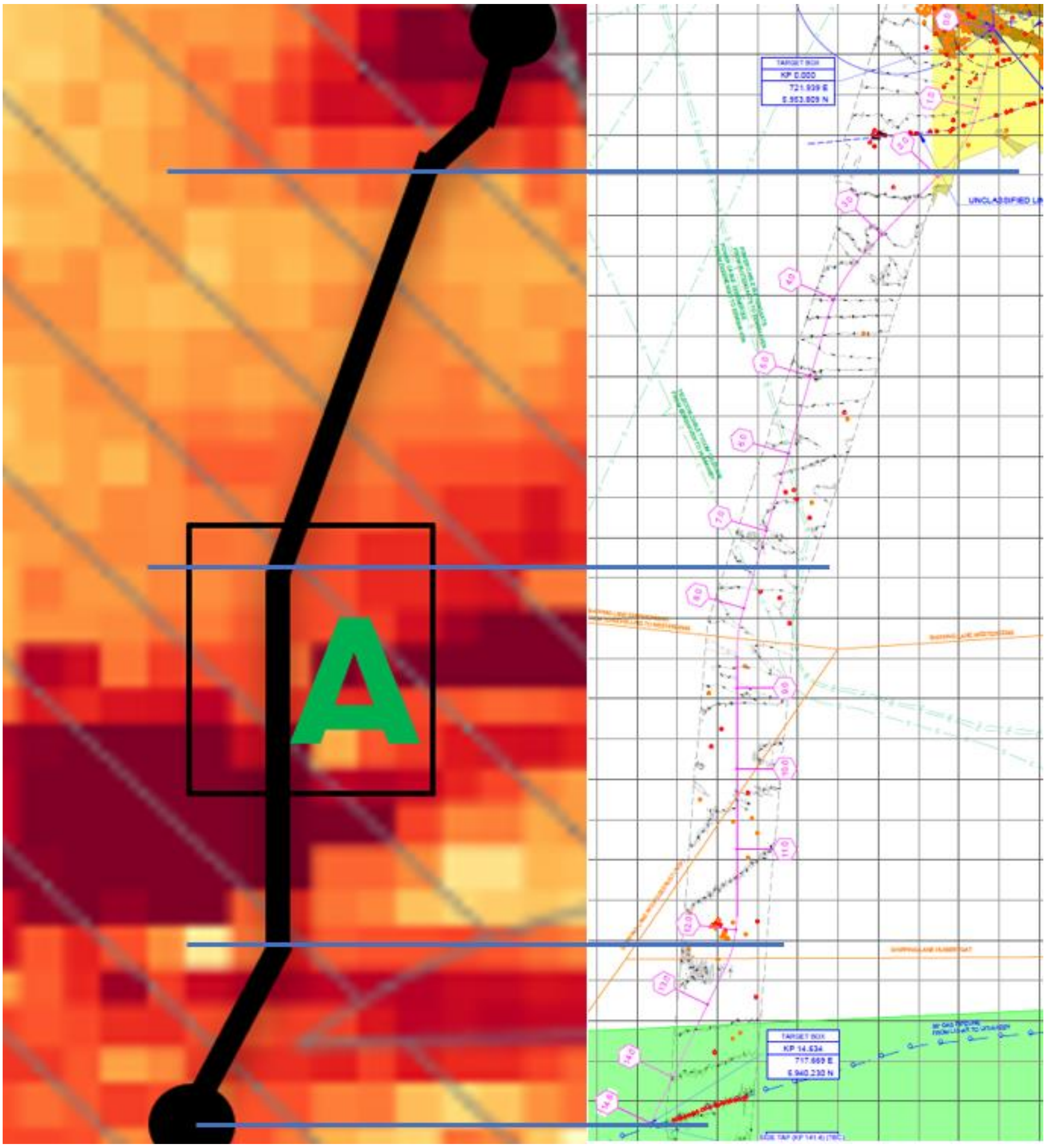


Figure 7 Shipping densities along the pipeline route

Table 15 Shipping densities along the pipeline route

From KP	To KP	Shipping density
0.0	2.0	45
2.0	7.5	15
7.5	12.2	45
12.2	14.6	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.

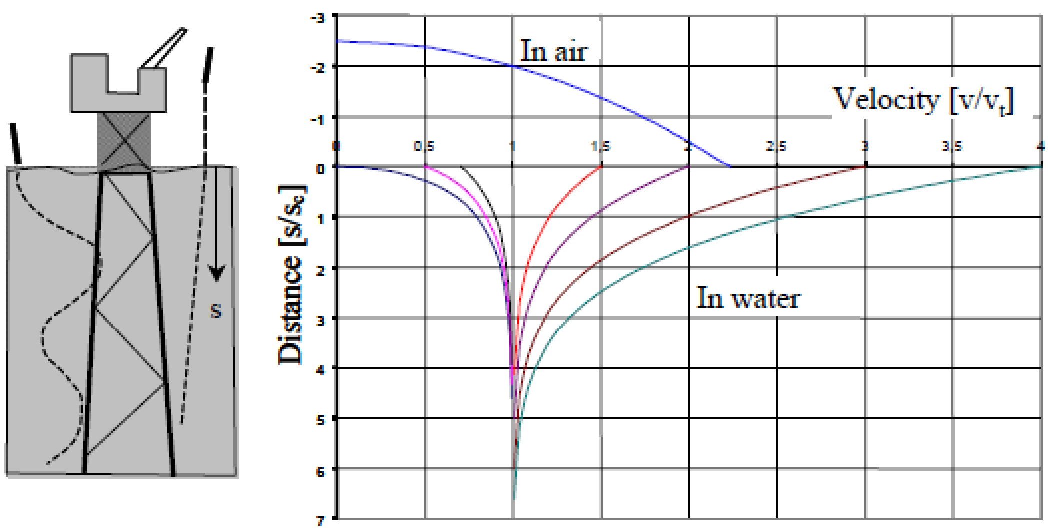


Figure 8, Velocity profile for objects falling in water [12]

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/m²]	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 .

$$Br = Bo + 2 \cdot h \cdot \tan{(90 - \varphi)}$$

$$Lr = Lo + 2 \cdot h \cdot \tan{(90 - \varphi)}$$

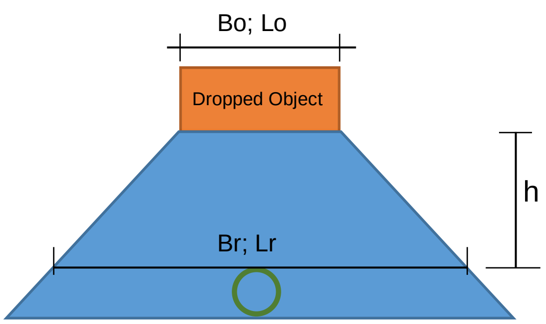


Figure 9 Rock dump geometric annotations

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 0-2.0 and 7.5-12.2 with high density shipping, 0.3 m of cover is required for the section KP 12.2-14.6, in the remainder between KP2.0-7.5, no cover is required.

With 40 mm of CWC, the burial depth in the designated shipping lanes (KP 0-2.0 and 7.5-12.2) 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			Control / Safeguard	Reference Document	Residual Risk			Action
						S	L	RR			S	L	RR	
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 S	Initial Risk L	Initial Risk RR	Control / Safeguard	Reference Document	Residual Risk S	Residual Risk L	Residual Risk RR	Action
	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.

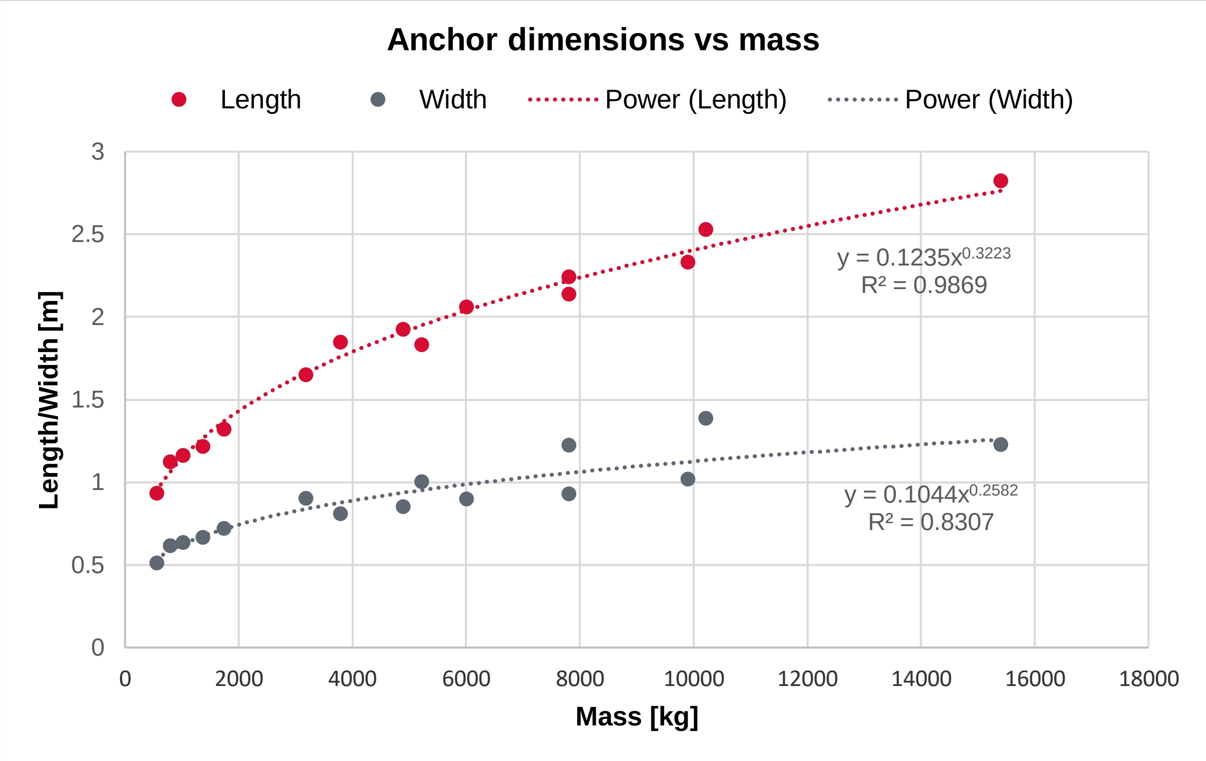


Figure 7, anchor size determination.

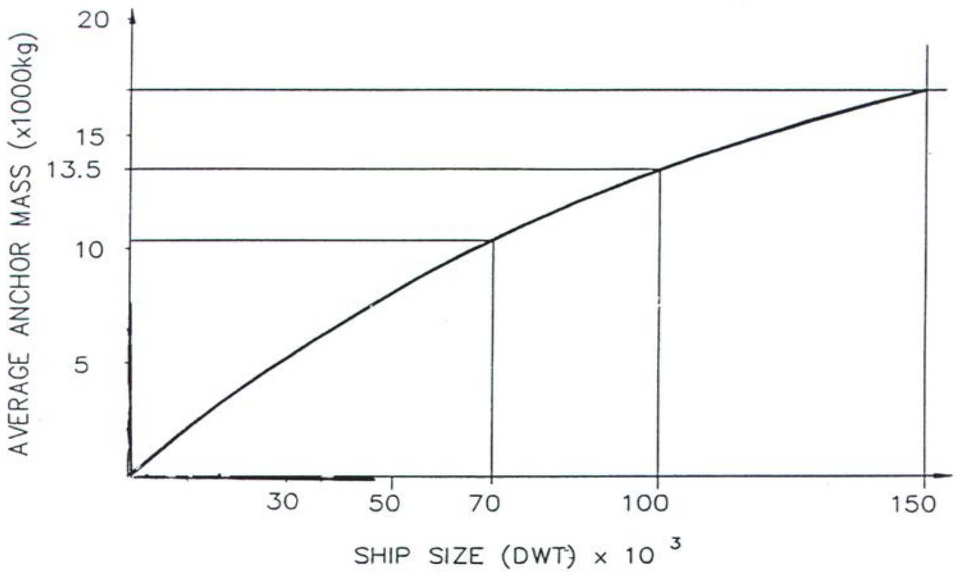


Figure 8, A.Ship size versus anchor mass

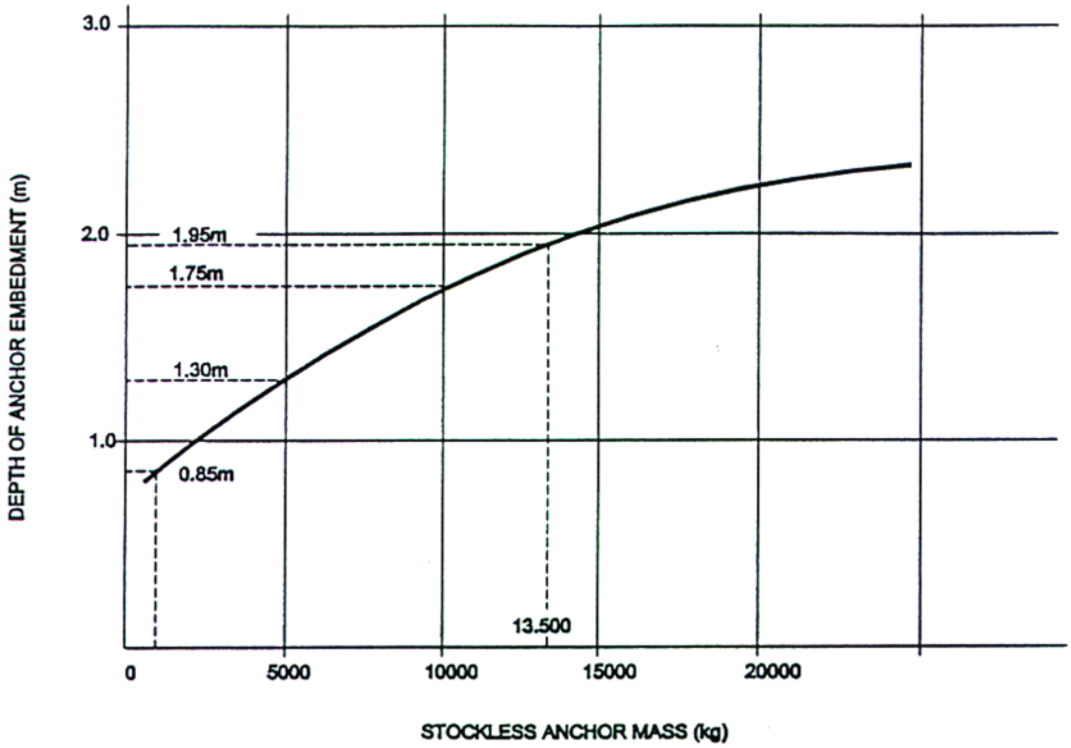


Figure 9, A.Penetration depths due to anchor drag versus anchor size

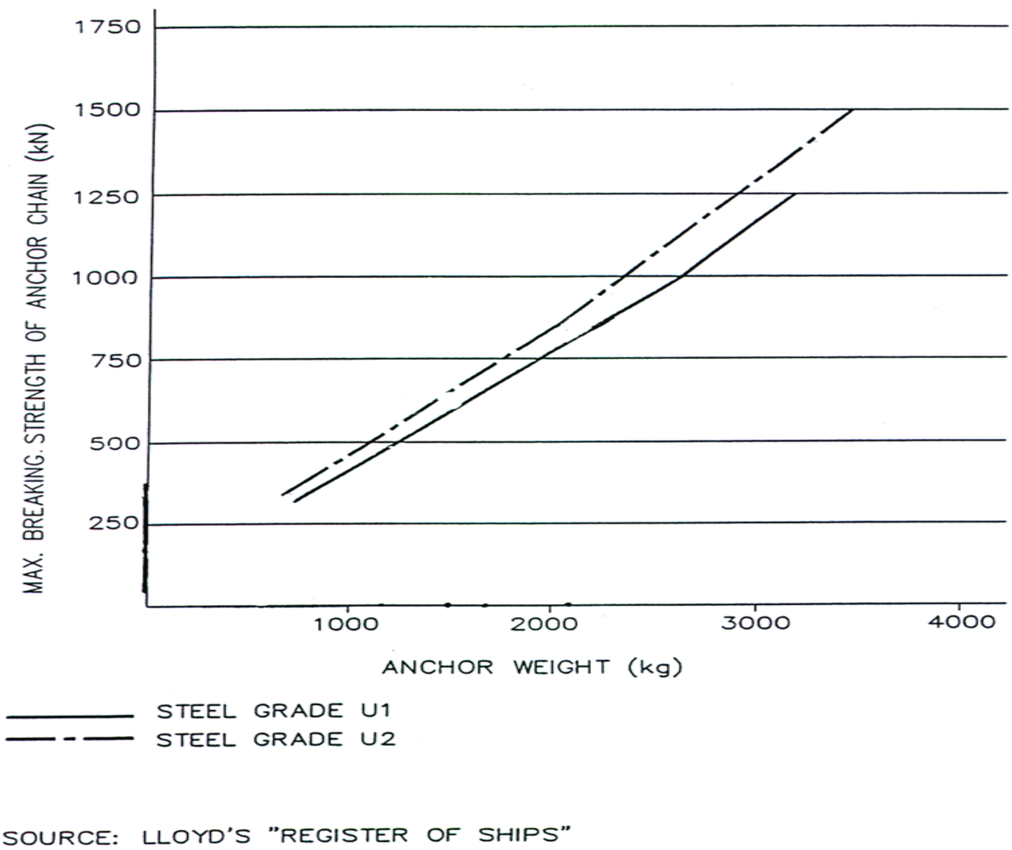
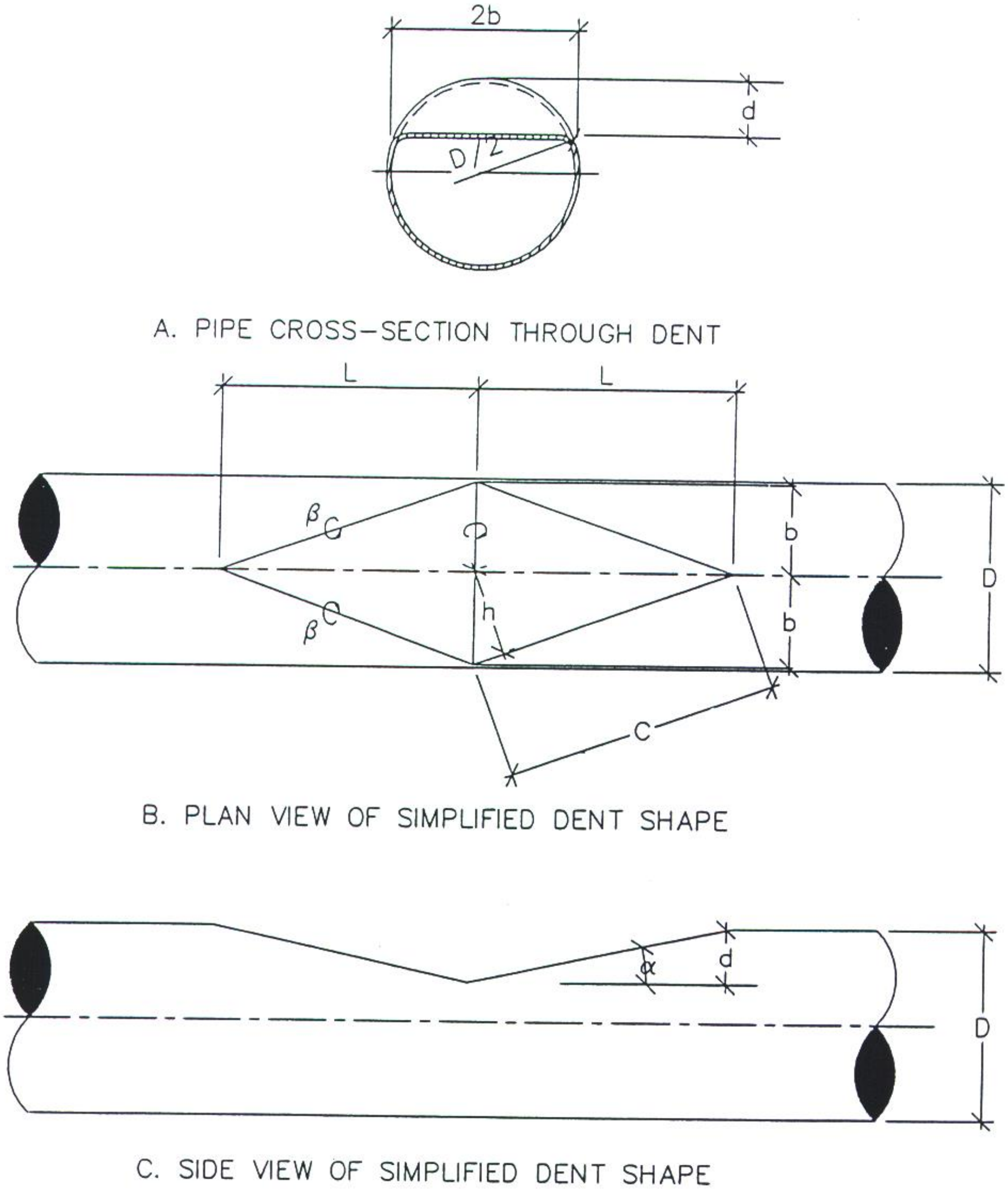


Figure 10, A.Anchor mass versus maximum breaking strength of anchor chain

D. Plastic deformation model



$\tan\alpha = d/L$

$\tan\beta = d/h$

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/m²]	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

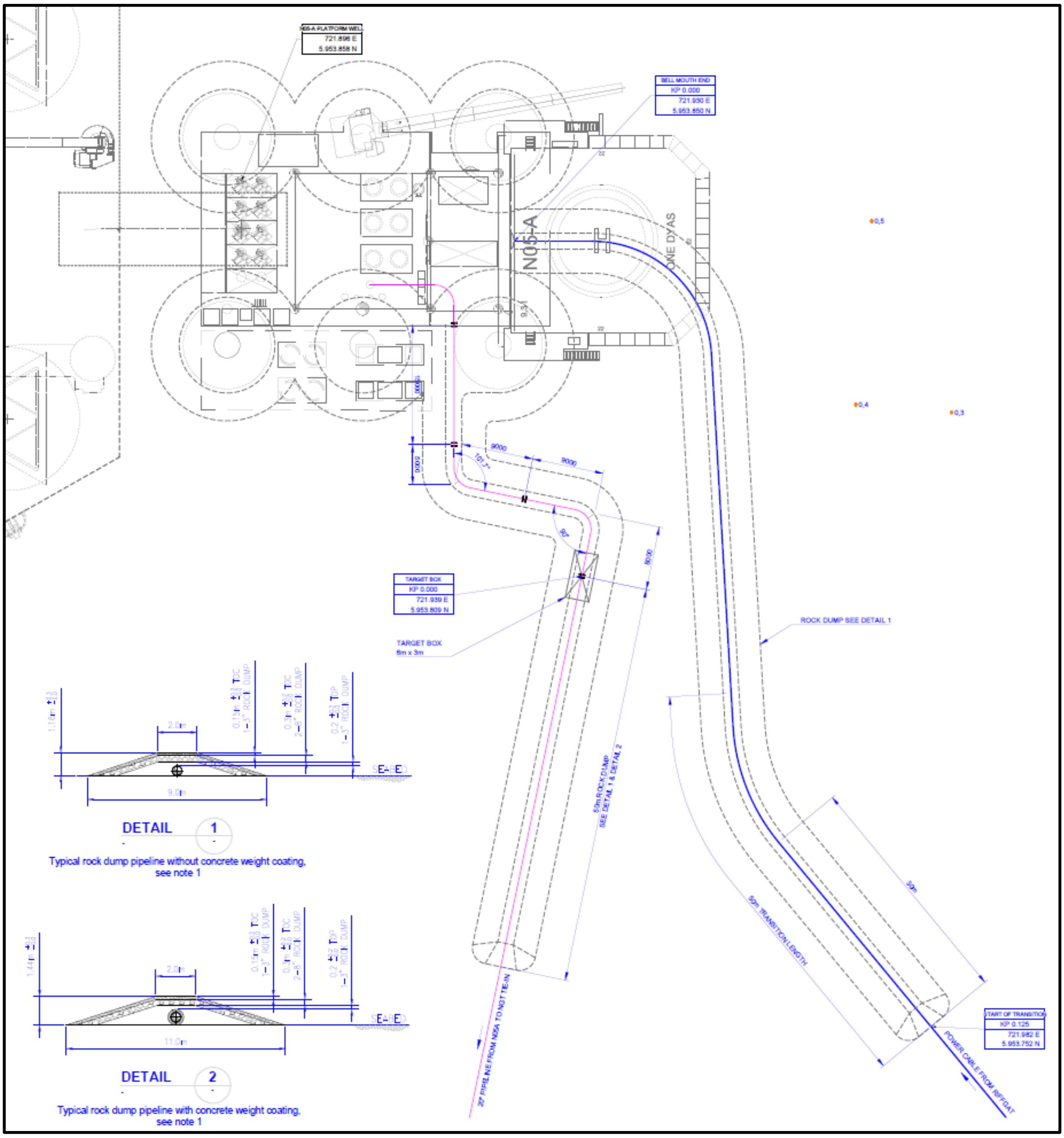


Figure 11, N05A-7-50-0-72051-01, Approach at N05A,